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The potential to recover higher value veneer products from fibre managed plantation eucalypts and broaden market opportunities for this resource: Part A

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The potential to recover higher value veneer products from fibre managed plantation eucalypts and broaden market opportunities for this resource: Part A

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by

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Executive Summary

This project, titled *the potential to recover higher value veneer products from fibre managed plantation eucalypts and broaden market opportunities for this resource,* has two parts:

- Part A investigates the genetics and wood quality of obtained from *E. nitens* and *E. globulus* grown in Tasmania and the genetic parameters that affect quality of rotary-peeled veneer, plywood and LVL.
- Part B investigates marketing rotary-peeled veneer recovered from native pulp wood in Tasmania. It looks at the potential to develop niche markets for the resultant products.

The objectives of this Part A of the study were to:

1. Provide baseline data on veneer quality and plywood properties of fibre-managed plantation *E. nitens* grown in Tasmania.
2. Identify the genetic parameters that affect quality of rotary-peeled veneer and plywood to guide selection of families for future breeding programs and to examine the compatibility of breeding for potentially conflicting objectives.
3. Assess the effectiveness of an acoustic sorting strategy and potential gain from segregation of logs for veneer and plywood production

The key outcomes, industry benefits and indication to future work included:

1. This project presents Australia's first large scale peeling trial for plantation *E. nitens* providing significant baseline data on plywood properties and veneer quality and the genetic parameters that underpin them. Results will help guide future breeding programs and direct research towards key processing parameters most likely to improve veneer quality and recovery and therefore commercial opportunities for peeled products from this resource.

2. Glue bond tests (for exterior use) were generally promising. Further work is required to improve and understand bond quality issues in younger (16yr) *E. nitens* resource.

3. Shear properties were poor for all resources tested at UTAS and EWPAA facilities, limiting F-Grade classification to F8 and below. Assuming shear strength could be increased beyond the observed limiting levels through process optimisation the resources tested would classify with F-Grades of F34 (*E.glob*), F17 (*E.ni26),* F17 (*TasOak / E.ni16*), F17 (*TasOak / P.rad*) and F11 (*E.ni16*).

4. Significant gains in veneer quality (and resultant product properties) may be achieved through appropriate drying of the plantation veneer.

5. Log steaming prior to peeling also needs to be evaluated to establish veneer quality (and end product) implications.

6. Plywood panels with optimised veneer sheet layup increased resultant panel stiffness by 18%.

7. Viable processing of short-rotation (16yr) unpruned E.ni will depend on increasing average stiffness properties through genetic selection of superior families, use of

acoustic sorting strategies to exclude low stiffness logs, process optimisation and recovery improvements as well as stiffness grading and alignment of veneers in panel construction.

8. High stiffness (and strength) values for *E. nitens* 26yr plywood panels (>14GPa, i.e. ≥F17), suggest opportunities for *E. nitens* resource on longer rotations (i.e. 20-25yrs). Further work is needed to analyse this potential including recovery of face grade veneers from pruned *E.nitens* logs.

9. Very high stiffness (and strength) values for the *E. globulus* resource indicate opportunities to utilise this species for peeled structural products. Further work is needed to examine material harvested from younger rotations i.e. 10-20yrs, (noting, the 33yr material in this project was opportunistic).

10. Acoustic correlations at log level (5.4m) were similar to those at billet level (2.4m) and were sufficient to indicate potential for acoustic segregation of long logs prior to merchandising.

11. The large dataset gathered for the 16yr *E. nitens* was useful in correlating AWV to veneer stiffness facilitating the segregation of logs into three stiffness classes. The practical benefit from an acoustic segregation strategy is likely to be the ability to identify low and high stiffness logs at the extremes of the stiffness distribution and utilise them appropriately.

12. Final engineered wood product (e.g. plywood and LVL) stiffness from plantation *E. nitens* could be improved through selectively breeding for higher standing tree AWV.

13. There were no adverse estimated genetic correlations between studied objective traits, indicating a breeding objective could be developed to include traits that would simultaneously improve desired properties in both pulpwood and RPV engineered wood products.

14. Implications for industry. The grade recovery into face material suitable for plywood was zero. This makes the resource as a stand-alone option unsuitable for plywood production. It may be suitable to supplement supplies of core veneer however industry usually has an over-supply of lower quality veneers and struggles to find uses for it. Commercial grade recovery is 80% C-D, 20% D-D plywood (which is later sold at marginal price). With no face grade ply, there is no commercial viability. For LVL production this is not as critical however there are limited LVL opportunities currently in Australia (only one LVL plant).

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Introduction

Overview

Tasmania has a significant and increasing supply of unpruned plantation eucalypt logs as well as an established and growing hardwood peeling capacity. Forestry Tasmania (FT) projects that about 300’000 m^3 of unpruned solid-wood logs will be available from State forest by 2012. Including projected supplies from private plantations, Tasmania will be producing over 2’000’000 m^3 hardwood pulp grade logs per annum. Two hardwood peeling facilities exist in Tasmania, currently milling native forest regrowth material. Over the next few years, the Tasmanian hardwood supply will be made up of increasing volumes of wood from unpruned eucalyptus plantations. Until now, this resource has generally been used for pulpwood and only very small proportions are peeled. Currently, rotary peeled (regrowth) veneer is exported.

Breeding programs have the potential to greatly improve wood properties according to the needs of the end-products. To-date there been extensive research on genetic improvement of *E. nitens* and *E. globulus* for utilisation in the pulp and paper industry (Borralho *et al.* 1993; Greaves *et al.* 1997; Hamilton and Potts 2008; Stackpole *et al.* 2010a; Stackpole *et al.* 2010b). Research on *E. nitens* and *E. globulus* breeding objectives for solid-wood products is not well developed (Borralho *et al.* 1993; Greaves *et al.* 1997), and definition of the traits to include in breeding objective for solid-wood products is the subject of recent and ongoing research (Blackburn *et al.* 2010).

This is a two part project linking: (A) genetics and wood quality; and (B) marketing, drawing on the research skills of the University of Tasmania and Forestry Tasmania. The project will define the likely plywood / LVL quality obtained from *E. nitens* and *E. globulus* grown in Tasmania, identify the genetic parameters that affect quality of rotary-peeled veneer, plywood and LVL, and develop niche markets for the resultant products. Due to the long-term nature of forest management, it is of critical importance today to breed and grow trees with properties optimal for wood-based materials of the future. Planting trees that can produce quality engineered wood products will diversify the market for plantation eucalypt logs, ensuring access to future high-value markets. The results will be of significant relevance for the national forest industry, particularly in Tasmania and Victoria where there is a significant unpruned resource of the two eucalypt species under investigation

Objectives

The data collected at each stage of this research will be assessed to determine:

- Effectiveness of an acoustic sorting strategy and potential value gain from segregation of logs for veneer production.
- Likely plywood / LVL quality obtained from new *E nitens* and *E. globulus* grown in Tasmania’s current plantation estate.
- Comparison of recoveries and end-product properties from material processed and manufactured in Australia and in China.
- *E. nitens* and *E. globulus* genetic parameters that affect rotary-peeled veneer, plywood and LVL quality. Results will guide selection of families for future breeding programs.

- Compatibility of breeding for potentially conflicting objectives, i.e. pulp and rotary-peeled veneer products from plantation *E. nitens* and *E. globulus.*
- Develop new markets for peeled products from eucalypt veneer.

Methodology

Overview

Figure 1 outlines the project methodology showing the raw materials used and data assessment applied at each stage. Material (from each species) was tracked from the forest through log, billet and veneer production processes (TaAnn / Forestry Tasmania Southwood). *E.ni16* and *TasOak* veneer was assessed at CHH Nangwarry using a Metriguard veneer grader, whist *E.ni26* and *E.glob* veneer was assessed manually at UTAS facilities. Plywood panels (made of veneer from single trees) were manufactured at CHH Myrtleford from a sample of the billets peeled for each resource. Tree identity was maintained throughout the process. Panels were ultimately tested at UTAS and EWPAA facilities to determine structural properties. Table 1 shows sample numbers at tree, billet and plywood level.

Table 1: Sample numbers at tree, billet and plywood stages

Species	No. of trees assessed	Billets peeled & Veneer assessed	No. of plywood panels
E. nitens **16yr**	534	452	30
E. nitens **26 yr**	50	49	30
E. globulus **33 yr**	24	18	13
TasOak	Not assessed	13	10

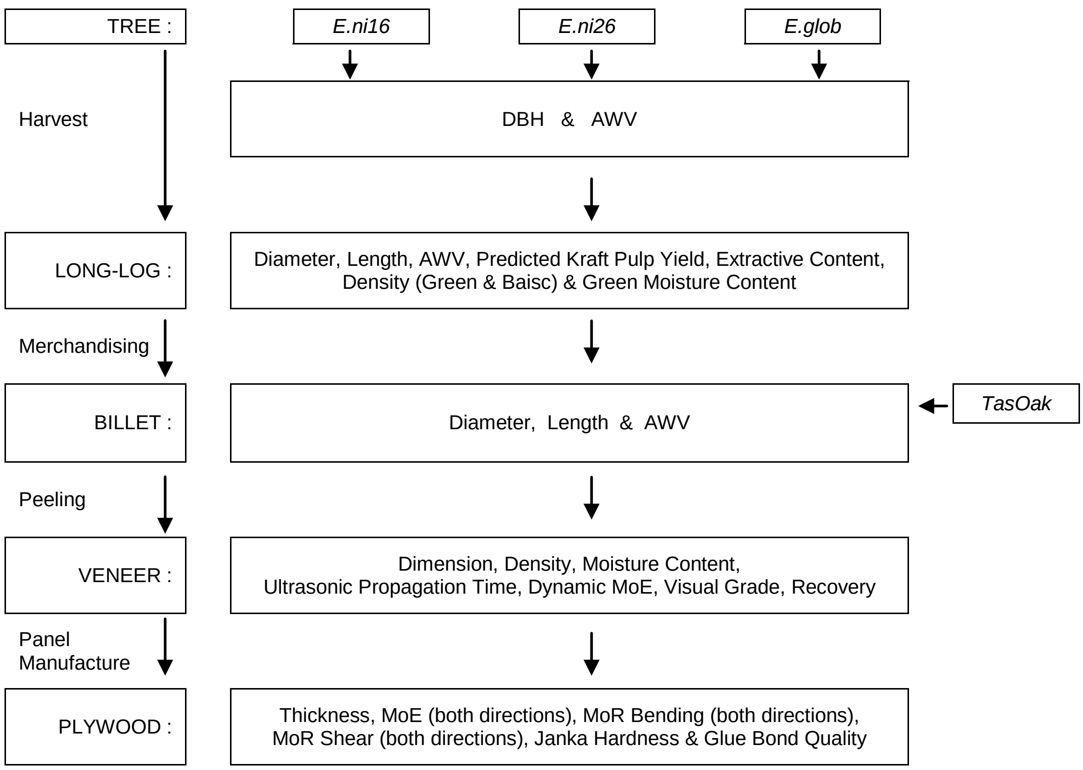


Figure 1: Project methodology

Resources Descriptions

The *E.ni* resources, and in particular the 16-year-old material, provide the core focus of the project as it was managed under fibre production silviculture (un-thinned and un-pruned). The 33yr *E.glob* resource was beyond commercial rotation age but was included taking advantage of resource availability and broad genetic structure. *TasOak* billets were included as reference material and were randomly selected from a production run at the peeler plant. Table 2 summarizes the resource data for the three plantation sites included in the study.

All surviving trees in the three trials were measured for diameter at breast height over bark (DBH) and assessed for stem-straightness using a six-point visual scale method purposely designed for Forestry Tasmania’s tree breeding program. To examine wood property traits, a sub-set of the progeny trial population was chosen. For the rotary veneer peeling trial standing trees had to meet a size criterion of over 23 cm diameter at breast height over bark (DBH) and be considered visually straight in the section of the tree the study log was to be extracted from.

Table 2: Plantation resource data summary

	Species	*E. nitens*		*E. nitens*		*E. globulus*	
	Harvest Age	16		26		33	
	Site	Tarraleah		Dial Range		Lisle	
	Latitude (South)	42^{o} 18’		41^{o} 10’		41^{o} 12’	
	Longitude (East)	146^{o} 27’		146^{o} 04’		147^{o} 18’	
	Altitude (m)	600		100		240	
	Rainfall (mm/year)	1200		1060		1060	
	Number of Trees	534		50		24	
Trees	Selection Details	3-5 trees x 110 Families		5 trees x 10 Families		4-5 trees x 5 Provenances	
	Silviculture	UT / UP		UT / UP		Thinned (330 stems/ha) UP	
	Planting Year	1993		1984		1977	
	Original Stocking Density [stems/ha]	1300		1100		1600	
	Log Position	Butt-log		2nd Log		2nd Log	
		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
	DBH Over Bark [cm]	28	3	40	4	35	3

16 year old *E. nitens* (Tarraleah) - *E.ni16*

The trial was established on a site previously occupied by a *P. radiata* plantation. Planting was undertaken in mid-1993 using stock from open-pollinated seed from 420 native-forest parent trees, sampled from twenty-eight localities extending over most of the natural range of *E. nitens* in the central highland region of Victoria. Genetically they encompassed three distinct races: Southern, Northern and Connor’s Plain (Hamilton *et al.* 2008). The trial used a randomised incomplete block design, comprising six replicates of twenty-one incomplete blocks, containing twenty families represented by a five-tree row plot. Fertiliser (100 g of superphosphate and 125 g of 20:10:0 N:P:K) was applied to each tree three months after planting. A total 548 trees from 110 families were selected for this study including five trees from each family, with the exception of two families with only four trees each. These selections were identified using the procedures outlined in Blackburn *et al.* (2010). Only three trial replicates were available for harvesting as part of this study and as far as possible, study trees were evenly represented across these replicates. The billets used to make veneer sheets for this study came from the base of the tree to give the maximum possible SED and maximize recovery of sheets (Figure 2).

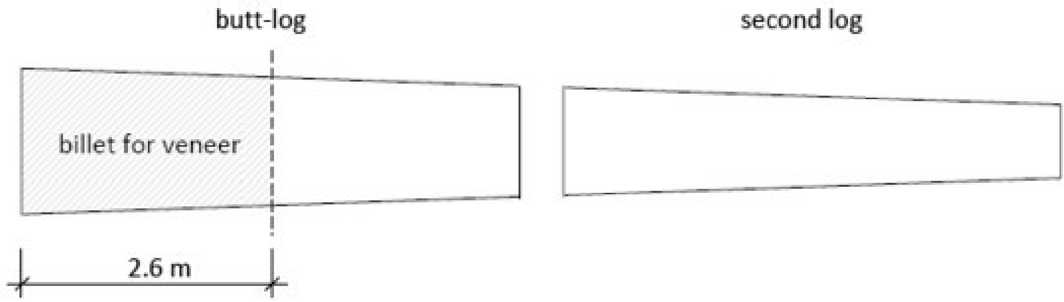


Figure 2: Merchandising pattern for *E.ni16* trees

26 year old *E. nitens* (Dial Range) - *E.ni26*

This trial was established using genetic material consisting of open pollinated progeny from 40 native forest families from the Toorongo Plateau (Southern race) in the central highlands of Victoria. Mother trees were growing as a pure stand in an open forest and stem diameters ranged from 35 to 110 cm. The trial design was a randomised complete block with single tree plots and 16 replications and received no primary fertilising. The trial was un-thinned and unpruned and survival at harvest was around 75 %. For this peeling trial a total of 50 trees encompassing 10 families (5 trees per family) were selected. In making family selections, preference was given to those families in the current FT deployment program whilst trees within family were randomly selected from those that met the required specification for size and form in the study log. When harvested, the average DBH over bark was about 37 cm. The basic density for these trees ranged from 411 to 633 kg/m^3 with an average of 520 kg/m^3. The peeler billet was merchandised from the base of the second (i.e. upper) log from the stem as shown in Figure 3, emulating the type of log available (for peeling) beyond the pruned section of the tree in FT's current 20-25 yr pruned *E.ni* silvicultural regime.

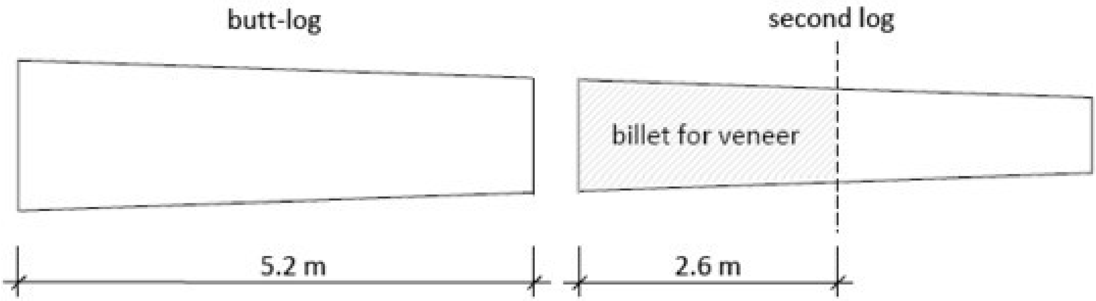


Figure 3: Merchandising the billet from *E.ni26* and *E.glob* trees

33 year old *E. globulus* (Lisle) - *E.glob*

This trial was established with seedlots collected from 31 native forest provenances in Tasmania and Victoria. The area covered by each provenance seedlot collection varied in diameter from about 10 km up to 30 km and seedlots where comprised of multiple families. Within a collection area, sample trees were at least 80 m apart and were selected according to the following criteria; trees were either dominant or codominant, stems were straight, there was no evidence of hybridisation, trees were well distributed throughout sample area, and the seed crop was good. The trial site was cultivated, but received no chemical weed control or fertiliser. Trial design was an incomplete latin square designs (in which complete replications were non-resolvable) with 6 replications, 31 incomplete blocks, and 25 trees per plot. The trial was thinned at age 13 to approximately 330 stems per hectare. For the peeling trials, 4-5 trees were selected from each of 5 provenances from across the geographic range of the species know to have contrasting wood properties (Apiolaza *et al.* 2005), these were; Geeveston, St Helens, King Island, Jeerelang and Otway Ranges. Trial trees within provenance were randomly selected from those that met the required specification for diameter and form in the study log. The average DBH over bark when harvested was about 34 cm. The basic density for these trees ranged from 509 to 675 kg/m^3 with an average of 600 kg/m^3. As per the *E.ni26* material the billets used to produce veneer came from the base of the second log of the stem (Figure 3).

In summary, the samples of *E.ni16* were analogous to the resource coming from stands managed for pulpwood whilst the *E.ni26* and *E.glob* were analogous to the knotty peeled resource (i.e. unpruned logs) from sawlog managed stands.

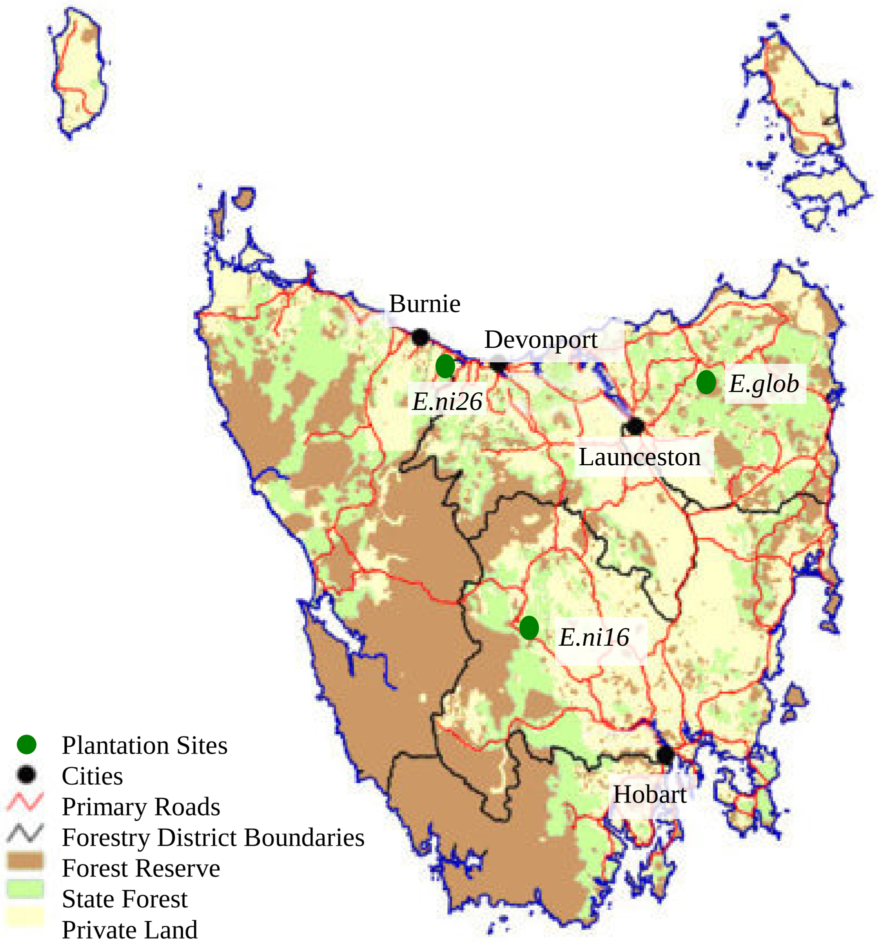


Figure 4: Map of Tasmania with harvest sites of *E.ni16*, *E.ni26* and *E.glob* (Forestry Tasmania 2010a)

Regrowth Tasmanian Oak

The regrowth *TasOak* resource was used as reference material for this project and was randomly selected onsite from current production. The 13 trees came from south Tasmania and were harvested in 2009.

Tree Selection & Harvesting

Standing tree assessment using NDE equipment

Prior to harvesting, the selected trees were assessed for acoustic wave velocity (AWV). The AWV of each tree was measured using the FAKOPP TreeSonic microsecond timer. The tool is designed to predict tree stiffness, measuring the stress wave time between start and stop transducer, this method is also called time of flight (TOF). To measure the AVW on the tree, the start and the stop sensor are driven at a 45° angle through the bark into the wood of the standing tree (Figure 5). To trigger a stress wave, the start transducer is hit with a hammer, automatically starting the microsecond timer. As soon the signal reaches the stop transducer the timer is stopped. The time between the sensors was measured over 1.2 meter length from 0.5m to 1.7m above ground level.

Figure 5: Fakopp TreeSonic driven at a 45° angle through the tree

Harvest and Log Assessment

The *E.ni* and *E.glob* trees were harvested, debarked and labelled with a log number at the site (Figure 6). The study trees were felled at an average stump height of 0.25 m and a 5.6 m (for butt logs) or 4.2 m (for 2nd logs) long study log was extracted. Before forwarding the study logs to the landing, a disk, approximately 50 mm thick, was cut from the upper (small) end of the logs from the *E.ni16* trial or the lower (large) end of the study logs from the older two trials so the sample disc was effectively from the same stem height in all trials. This disc was plastic wrapped to prevent drying and then refrigerated at 2°C prior to lab analysis for green density, basic density, green moisture content, extractive content, predicted cellulose content and Kraft pulp yield.

Figure 6: Harvesting and marking *E.glob* logs

The butt-logs of *E.ni16* and the upper logs of *E.ni26* and *E.glob* were assessed for AWV using two resonance method tools, the Hitman Director HM200 and a Fakopp Resonance Log Grader (Figure 7 to Figure 9). The logs were then transported to TaAnn Southwood. Logs were generally peeled within two weeks of harvest date.

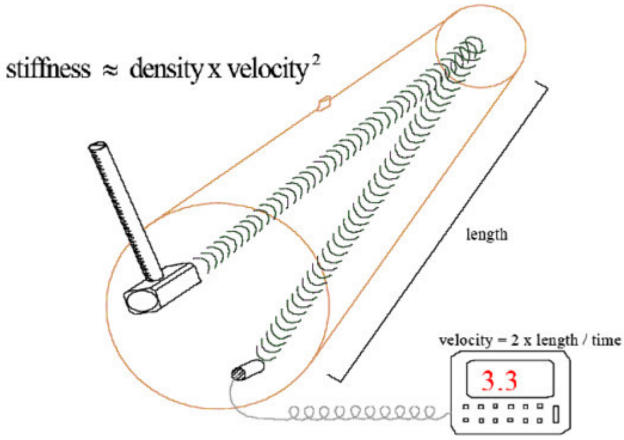


Figure 7: Scheme of acoustic wave velocity measurement

Figure 8: Measurement of AWV using the Fakopp Resonance Log Grader and a hammer

Figure 9: Measurement of AWV using the Fibre-gen Hitman Director HM200 and a hammer

Wood quality testing of log-end disc

Assessment of basic density

Within two to four months, log disks removed from study logs were band-sawn to produce a pith-to-bark wedge approximately 30 degrees in angle. This wedge was used to determine basic density using the water displacement method (TAPPI 1989) and green density.

Assessment of cellulose content, Kraft pulp yield and extractives

Each disk removed from the study logs was band sawn to produce a pith-to-bark plinth, 10 mm in width and the full depth of the disk. This plinth was air-dried to approximate 12% moisture content. The plinths were ground to wood meal using a 3383-L30 Wiley Mini Mill. A Bruker MPA FT-NIR, Model instrument was used to collect spectra across a wave number range 12 000 – 4 000 cm-1, at an optical interval of 8 cm-1. Spectral analysis was performed within the Bruker QUANT routine within the OPUS 5.5 software package (Bruker 2005).

From the analysis, KPY, CC and extractives were predicted using existing calibration models developed from woodmeal of known KPY, CC and extractives.

Log assessment and veneer peeling

Log Assessment

At the peeler-mill (Ta Ann Southwood, Geeveston), log identity numbers were transferred to the butt ends of each log before and after merchandising maintaining tree identity through the process. The billets were cut from the large end of the log into 8ft (2.54m) billets. Following merchandising billets were laid out for diameter, length and AWV measurement (Figure 10). A sample of 13 regrowth *TasOak* logs was randomly selected from a production run to provide *TasOak* reference material. These billets were also assessed at the mill (for billet diameter, length and AWV).

Figure 10: E.ni16 billets for acoustic assessment in the TaAnn log yard

Veneer peeling and tracking

The billets were fed into the peeler after assessment in the log yard (Figure 11). The order in which the logs were peeled was expected to be sufficiently randomised across families/provenances through the processes harvesting, transportation and merchandising. The billets were peeled at normal rates of production and as per standard mill practice at the Ta Ann mill were not steamed prior to peeling.

Figure 11 : Billets loaded onto the peeler lathe

To maintain tree identity during the peeling process a spray based veneer tracking system (SBVT) was developed to spray a unique identification code on the surface of the veneer from each billet (Figure 12 to Figure 15). The SBVT uses a series of five solenoid controlled spray guns that are programmed to fire in short or long bursts providing 64 unique log codes manually activated from a control box. The number of unique codes can be increased by fitting additional spray heads, using different color combinations, or further combinations of spray activation time (e.g. short-medium-long). The SBVT was installed on the lathe out-feed and sprayed the surface of the veneer from each billet with a unique code. To ensure that all veneer sheets (auto-clipped from veneer ribbon) were coded the SBVT was set up to spray every 300 milliseconds. With a feed rate of approximately 120m/min this resulted in a code mark every 60cm.

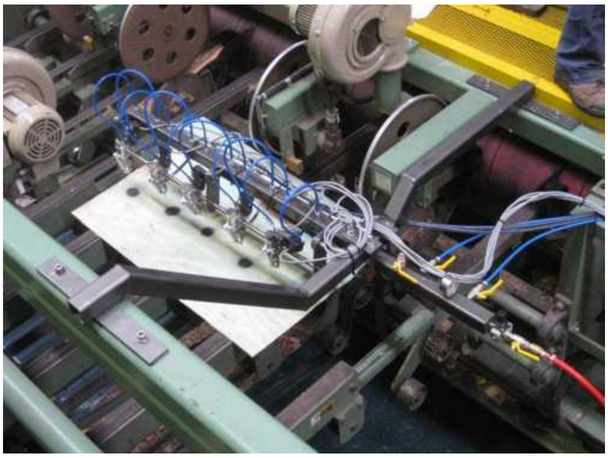


Figure 12: Installation of veneer tracking system

Figure 13: Spray coded veneer

Figure 14: Spray system control box

Figure 15: Operating the spray system

Veneer was peeled to maximise recovery of long-grain sheets clipped every 4ft to produce standard 8’ x 4’ veneer sheets. Target thickness was 2.6mm for the plantation material (2.65mm for *TasOak*) to produce a 2.4mm veneer sheet.

As each billet was loaded on the lathe billet identity and sequence number were recorded. Due to the large number of *E.ni16* billets, they were peeled in batches to overcome the limited number of unique spray codes (Figure 16). Tree identity was thus confirmed by the combination of batch ID (from the veneer pack) and the individual veneer sheet code. Short grain veneer was not tracked.

Figure 16: Green *E.ni16* veneer peeled and stacked according to batch number

Veneer drying

After peeling, veneer packs were labelled and transferred to the drier (Figure 17). Research staff were posted at the infeed and outfeed to ensure correct sequencing of veneer sheets through the drying process. At the end of the drier the sheets were carefully stacked according to batch (*E.ni16* only).

Figure 17: *E.ni16* veneer at drier infeed (spray code on underside)

The standard *TasOak* drying schedule was used to minimize commercial interruption. Target MC was 6-8% at a feed rate of 2.5m/min. Feed rate was adjusted according to MC measurements taken on the dried veneer exiting the drier. As *E. nitens* dries faster than *TasOak*, feed-rate was increased to minimize over-drying and maximise throughput. The drying schedule with targeted temperatures and relative moisture content in each zone is shown in Table 3. After drying, the batches were plastic wrapped (Figure 18) and transported to UTAS facilities.

Table 3: Drying schedule with targeted temperature and relative moister in each Zone

Zone	1S	1st	2nd	3rd	4th	20S
Heat [C°]	165	180	180	178	170	165
Moisture [%]	18	30	35	20	-	11

Figure 18: Dried and wrapped *E.ni16* veneer ready for shipping

Veneer assessment

Veneer sheets were placed on a purpose built assessment table with transparent surface and mirror underneath to enable tree ID to be determined from the underside of each sheet. This precluded any need to flip the sheet (to reveal the spray code) and also minimised sheet handling and therefore likelihood of sheet damage (Figure 19 and Figure 20).

The sheets were labelled by hand with tree ID and sheet number and visually graded according to standard AS/NZS 2269.0:2008 (Standards Australia 2008). The *E.ni16* and *TasOak* veneer was wrapped in plastic and shipped to the CHH mill in Nangwarry (South Australia) for automated assessment using (Metriguard veneer grader DME 2800). Due to the shut-down of LVL production at the Nangwarry mill *E.ni26* and *E.glob* veneer was assessed manually at the UTAS lab.

Figure 19: De-coding and visual grading veneer at the UTAS lab

Figure 20: Mirror underneath the grading table to identify Tree ID sprayed on each veneer sheet

Visual grading

Each veneer sheet was visually graded according to standard AS/NZS 2269.0:2008. The standard quality veneer grades A to D are limited by imperfections such as bark gum, resin pockets, gum veins, unfilled holes, splits, patches and knots. As shown in Figure 21, cumulated width of knots, patches, holes and splits measured on any 300 mm line across the grain are often the limiting factor. For grades A and B quality hardwood veneer, the aggregate dimensions of all imperfections should not exceed 45 mm measured on any 300 mm line, while for grade C and D not more than 75 mm. Veneer sheets that fall short of grade D (i.e. "Failures") were marked with an F (Figure 22).

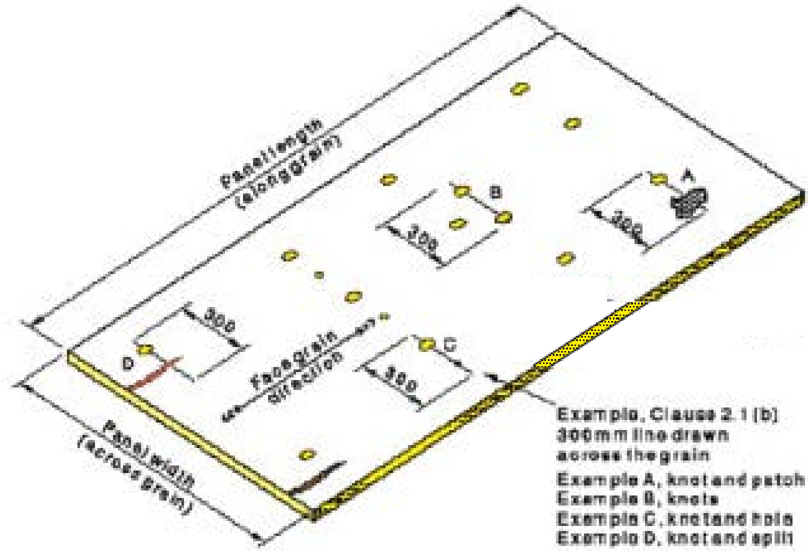


Figure 21: General visual grading guidelines for veneer sheets of structural plywood (AS/NZS 2269.0 2008)

Figure 22: Veneer sheet failing visual grade due to excessive knots

Dynamic MoE determination

The *E.ni16* and *TasOak* veneers were assessed at the CHH mill in Nangwarry using the automated veneer grader (Metriguard DME 2800).

The Metriguard veneer grader (Figure 23) estimates the dynamic Modulus of Elasticity (MoE_{dyn}), and determines specific gravity, average and peak moisture content, sheet width and thickness. The Metriguard MoE_{dyn} calculation adjusts for sheet temperature, MC and skew using a proprietary formula. The Metriguard uses a transmitter wheel that rolls over the veneer to introduce an ultrasonic signal into the veneer. A receiver wheel on the other side of the sheet picks up the signal and records the time taken. The distance between the wheels was 222.25cm. Specific gravity (SG) and moisture content was measured via resonator cavities suspended above and below the veneer sheet whilst infra-red sensors determine sheet temperature.

Figure 23: Metriguard veneer grader at Carter Holt Harvey - Nangwarry

The MoE_{dyn} for *E.ni26* and *E.glob* was manually assessed at the UTAS lab facilities and was determined with a Fakopp Ultrasonic Timer UT-52/2009. A sender and receiver were fixed at a distance of 1529 mm on the bottom of a steel load (200N) to ensure proper ultrasonic transmission. A pneumatic system was constructed and installed to operate the lifting of the ultrasonic timer to and from the grading table (Figure 24).

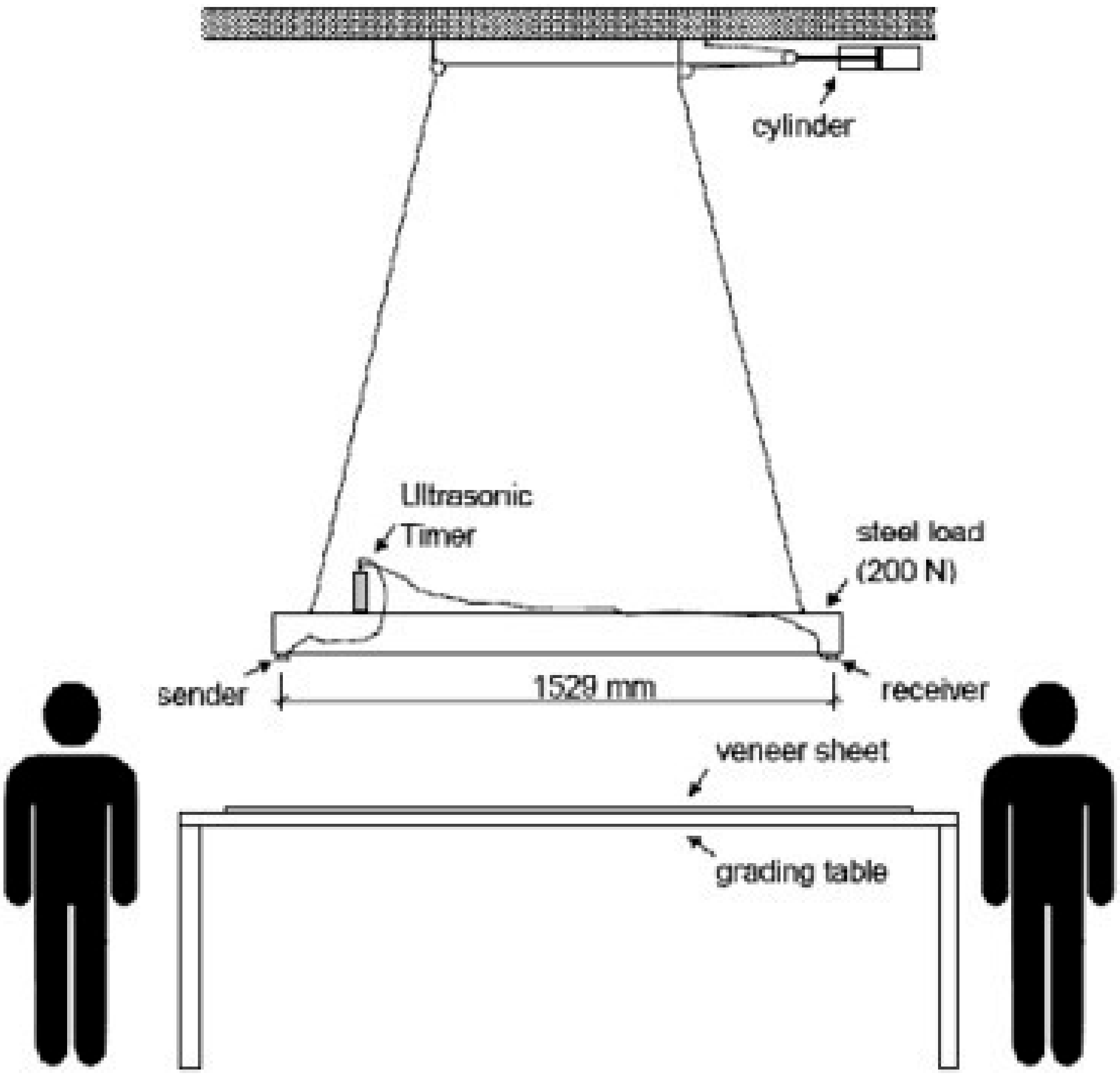


Figure 24: Set up of manual dynamic MoE assessment with Fakopp Ultrasonic Timer

Three readings per sheet along the grain were taken to get an average MoE_{dyn} for each veneer sheet. Two readings were taken approximately 200 mm from the edge and one measurement in the sheet middle (Figure 25).The number of sample points used in this method is much lower than the multiple sampling used by a Metriguard.

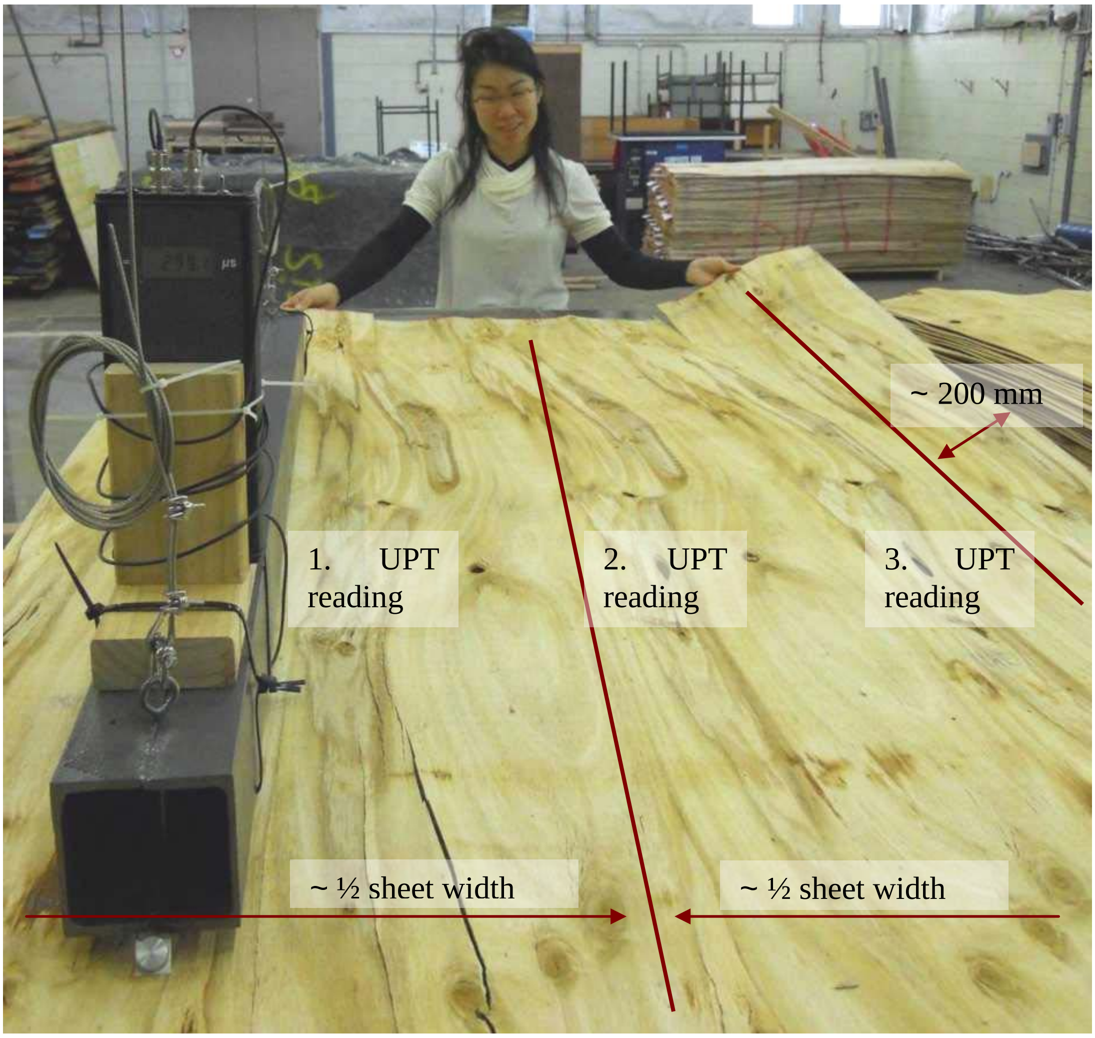


Figure 25: Ultrasonic Timer reading placement on veneer sheets

To calculate the velocity, Equation 1 was used. The distance between the transducers was 1529 mm. A time correction value of 4.4 μs (determined by the manufacturer) was subtracted from the measured time.

Equation 1: Velocity determination (Fakopp 2010)

$$V = \frac{(1000 * l)}{(t - t_{corr})}$$

Where

V =	velocity of the sonic through the material [m/s]
l =	distance between transducers [mm]
t =	measured time [μs]
t_{corr} =	time correction [μs]

The MoE_{dyn} of the manually assessed veneer sheets was calculated according to Equation 2. Density for each sheet was determined directly after the UPT measurement and is described in Section 3.5.3.

Equation 2: MoE$_{dyn}$ (Rennert et al. 1986)

$$MoE = \rho * V^2$$

Where
MoE = dynamic modulus of elasticity [Pa]
ρ = density of material [kg/m^3]

Density

The density of *E.ni26* and *E.glob* veneer sheets was determined according to AS/NZS 2098.7:2006 using (non-destructive) measurements of mass and volume and calculated according to Equation 3. The volume was determined by measuring thickness, width and length. Measurements were taken manually with two PC-connected callipers (Mitutoyo CD-8"GM, Mitutoyo CD-8"C). Thickness was measured at four points of the sheet (Figure 26) and mean value determined.

Equation 3: Calculation of veneer sheet density (AS/NZS 2098.7 2006)

$$\rho = \frac{m}{T \times L_1 \times L_2} \times 10^6$$

Where
m = mass of the test piece [g]
T = thickness of the test piece [mm]
L_1, L_2 = lengths of the sides of the test piece [mm]

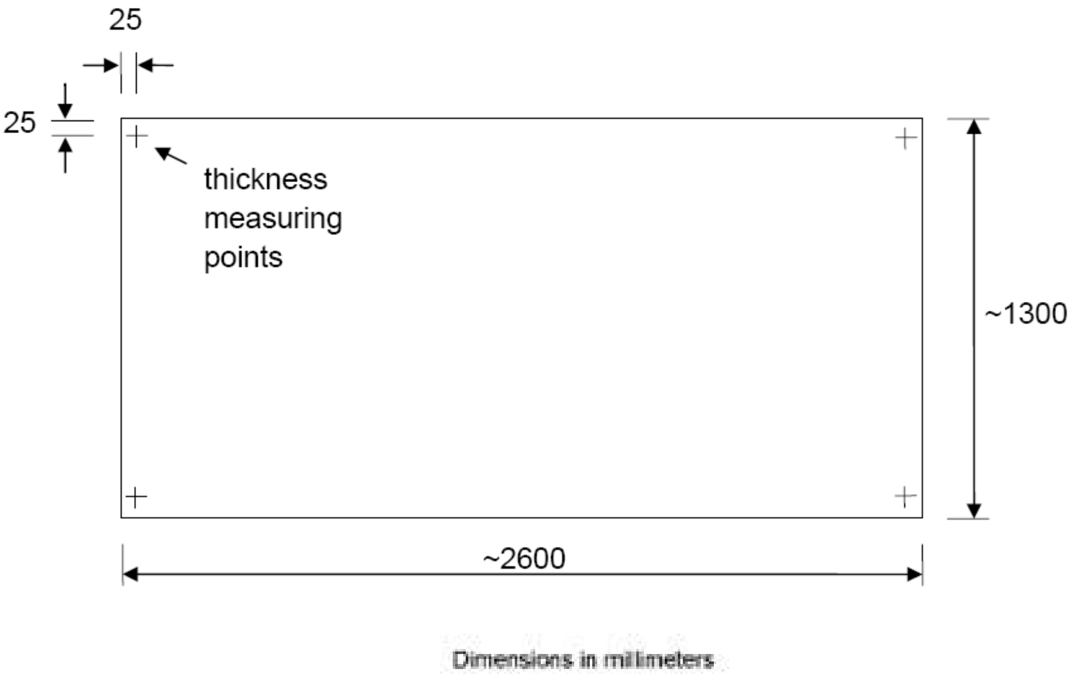


Figure 26: Location of measuring points for thickness according to AS/NZS 2098.7:2006

Three measurements of length and width were taken (Figure 27) according to AS/NZS 2098. The mean value of the measurements in each direction was used as the length and width of each sheet.

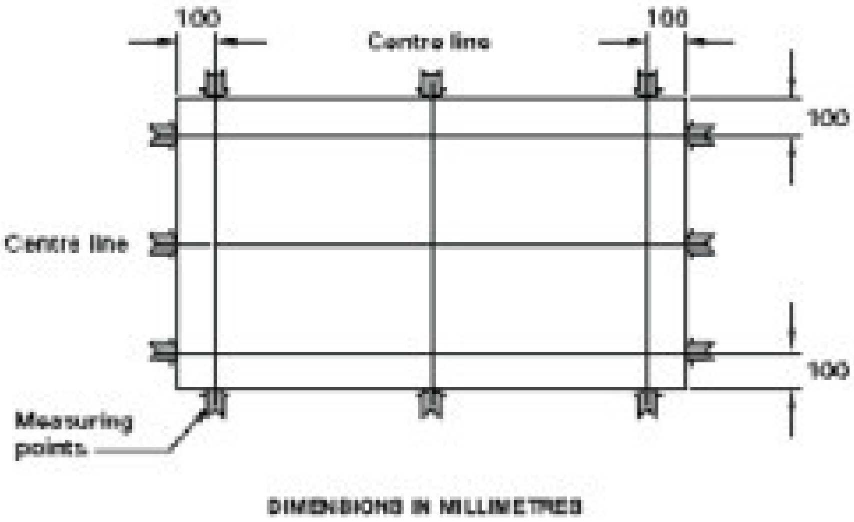


Figure 27: Location of measuring points for length and width (AS/NZS 2098.4 2006)

A purpose-built weighing table was used to accurately determine veneer sheet weight. The weighing table was constructed of 40 x 40 mm aluminium riveted together (Figure 28). Four beam load cells were fixed on the bottom of the aluminium framing near the corners. The load cells were connected to a display showing the total sheet weight (Figure 29 and Figure 30) and have an accuracy within 1% as required by AS/NZS 2098.7.

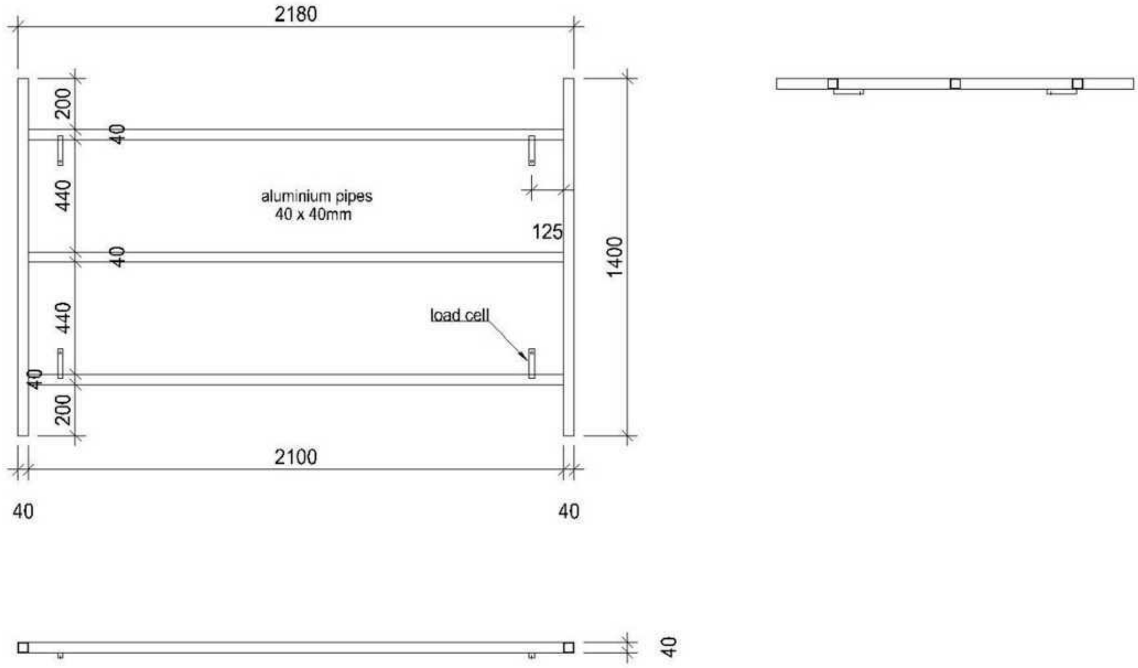


Figure 28: Design of veneer sheet weigh table (dimensions in mm)

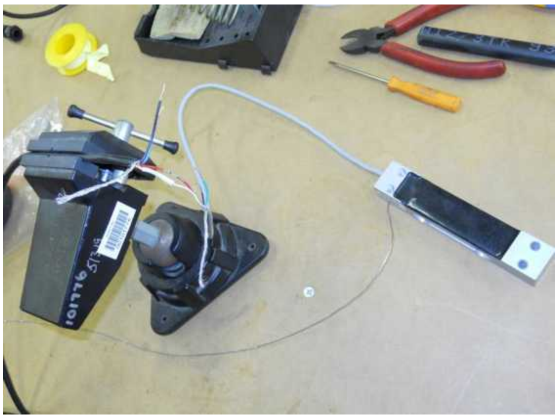


Figure 29: Load cell prepared to connect to the weighing read out equipment

Figure 30: Weighing read out equipment

Moisture content

MC was determined non-destructively using a hand-held capacitance MC meter. The mean value of three readings was taken as an average value.

Equation 4 was used to adjust the density of the sheet to density at 12 % MC.

Equation 4: Adjusting to a density at 12% moisture content (AS/NZS 2098.9 1995)

$$\rho_{12} = \rho \times \frac{100 + 12}{100 + MC}$$

Where
ρ_{12} = density at 12% MC [kg/m^3]
MC = moisture content of the test piece [%]

Veneer selection

A total of 85, 5-ply (12mm) plywood panels were manufactured using veneer from individual trees, i.e. a plywood panel was produced using veneer from an individual tree. Thus individual tree identity was maintained from tree, log, billet, veneer through to plywood panel.

Panels were pressed on two separate occasions with details provided in Table 4. The first pressing trial was focused on the *E.ni16* and the *TasOak* and *Pinus radiata* control panels. Due to the large number of trees from the *E.ni16* resource the first pressing (15 panels) was based on trees selected from three stiffness classes generated according to the average veneer MoE_{dyn}: high ≥ 12MPa > medium ≥ 10.5MPa > low, to provide a broad representation of plywood properties. In this initial pressing trial sheet order for each panel was randomized (i.e. there was no selection based on estimated sheet stiffness).

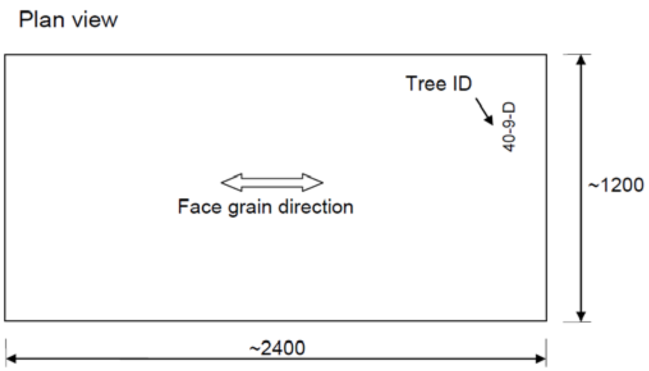
Table 4: Selection of tree and veneer for pressing plywood

	Pressing Trial 1 (11th Feb 2010)	Pressing Trial 2 (10th June 2010)	Number of samples	Selection of trees for panel manufacture	Selection of veneers within each panel
E. nitens **16yr**	•		15	stiffness class	random
TasOak / P.rad	•		10	random	random
P. radiata	•		5	random	random
E. nitens **16yr**		•	15	Stiffness class	Stiffness optimised
E. nitens **26yr**		•	30	family	Stiffness optimised
E. globulus **33yr**		•	13	provenance	Stiffness optimised
TasOak / E.ni16		•	2	random / family	Stiffness optimised

For the second pressing trial trees were selected for plywood manufacture to provide data across the families (*E.ni16* & *E.ni26*) and provenances (*E.glob*) represented for each resource. The *E.ni16* material was selected across the range of "stiffness classes" (5 low, 8 medium and 2 high stiffness) from trees that produced at least the five required veneer sheets. For *E.ni26* one panel was manufactured for three trees from each of the 10 families (total of 30 panels). For *E.glob* one panel was manufactured for three trees from each of the five provenances, however, only two panels were made for two of the provenances due to insufficient veneer from sampled trees (total of 13 panels). All panels pressed in the 2nd trial were stiffness optimised in that the stiffest veneers (i.e. those from the outside of the billet) were placed on the outside of the panel.

Plywood manufacture

As described above panels were pressed on two separate occasions at CHH-Myrtleford according to commercial standards (AS/NZS 2269.0:2008). Panels are described as "12-24-5", i.e. 12 mm thick plywood with a nominal veneer thickness of 2.4 mm with five plies (Figure 31). All veneer sheets for each panel came from the same billet (i.e. tree).



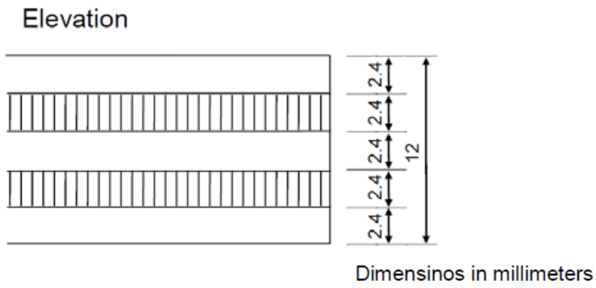


Figure 31: Nominal dimensions and lay-up of plywood panels, dimensions in mm

Core (cross-band veneer sheets were separated from surface veneers and cut with a bandsaw (Figure 32). The glue used was the current standard formula phenol formaldehyde resin. The glue was applied with rollers to both sides of the crossband veneers with a spread weight range of 340 g/m2 to 390 g/m2 (Figure 33). Stacks of 15 panels were placed in a cold press after initial lay-up (Figure 34). Cold pressing time was 10.5 minutes during the trials at a pressure of 21’000 to 24’000 kPa. Pre-pressed panels were then placed on heating plates in preparation for the hot press (Figure 35). For the trial 12 mm plywood panels, hot pressing was 5 minutes (137°C), at a pressure between 24’800 to 28’800 kPa.

Figure 32: Cutting veneer stack of crossband sheets

Figure 33: Weighing of Veneer sheet to control amount of glue applied

Figure 34: Veneer lay up by stacking sheets after applying glue on crossband veneer

Figure 35: Sheets placed on heating plate for hot press

Plywood structural property assessment

Test pieces were cut from each panel to determine structural properties using the cutting pattern shown in Figure 36. Samples were prepared for testing by cutting with a CNC router (Figure 37) and a circular saw (dashed lines PSpe, PSpa and Jpa). MoR, MoE, panel shear and bond quality were tested to determine the F-grade classification for the resultant plywood. Janka hardness was also tested to indicate suitability for container flooring.

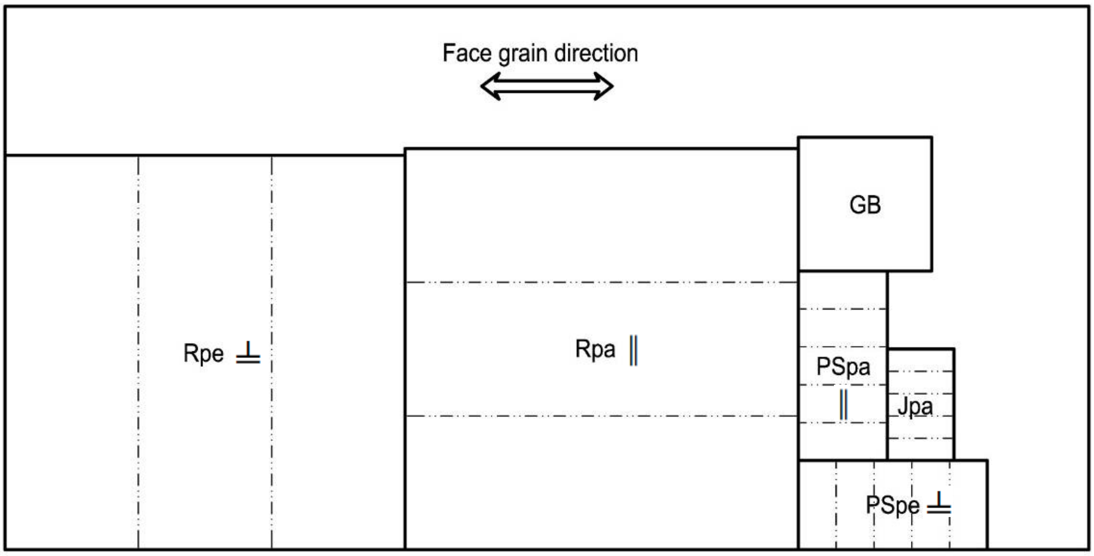


Figure 36: Cutting pattern for test pieces from plywood panels

Where

R_{pe} =	3 bending test pieces perpendicular to face grain, 300 x 885 mm
R_{pa} =	3 bending test pieces parallel to face grain, 885 x 300 mm
PS_{pe} =	5 panel shear test pieces perpendicular to face grain, 85 x 200 mm
PS_{pa} =	5 panel shear test pieces parallel to face grain, 200 x 85 mm
J_{pa} =	5 Janka hardness test pieces parallel to face grain, 150 x 50 mm
GB =	1 panel glue-bond test piece, 300 x 300 mm

Figure 37: CNC router cutting test pieces from plywood panel

Details of plywood testing are shown in Table 5. Sample numbers per panel exceeded requirements of AS/NZS 2269.1 to maximise result certainty. All samples were tested by UTAS except glue bond tests (EWPAA) and the bending tests (MoE / MoR) from the first pressing trial (carried out by CHH-Myrtleford). Shear and Janka hardness was not tested for the first pressing trial panels due to loss of samples at the mill.

Table 5: Test piece sample numbers / panel for MoE / MoR, shear strength, Janka hardness and glue-bond quality

	Number of panels	Bending ‖ and ⊥	Panel shear ‖ and ⊥	Janka hardness ‖	Glue bond[b] ‖
E. nitens **16yr**[a]	15	1	*	*	1
TasOak / P.rad	10	1	*	*	1
P. radiata	5	1	*	*	1
E. nitens **16yr**	15	3	2	3	1
E. nitens **26yr**	30	3	2	3	1
E. globulus **33yr**	13	3	2	3	1
TasOak / E.ni16	2	3	2	3	1

Notes [a] MoE / MoR tests by CHH-Myrtleford (1st pressing trial)
[b] Tested by EWPAA
[*] No data available

Glue-bond

All glue-bond samples were shipped to Brisbane and tested by EWPAA according to AS/NZS 2098.2 and AS/NZS 2098.4. Glue-bond pass criteria for A-bond quality used those as described in AS/NZS 2269.0. The glue-lines in a single test piece prepared from each sample had to achieve a bond quality value (Table 6) of not less than 2 in any single glue-line and an average of not less than 5.

Table 6: Bond quality scale with estimated wood failure in % and bond quality value (AS/NZS 2098.2 2006)

Estimated wood failure (%)	Bond quality value
0 to 5	0
6 to 15	1
16 to 25	2
26 to 35	3
36 to 45	4
46 to 55	5
56 to 65	6
66 to 75	7
76 to 85	8
86 to 95	9
96 to 100	10

Due to poor glue-bond results from previous in-house eucalypt pressing trials, a series of glue bonding tests were carried out at the Hexion laboratories prior to any pressing of test panels at CHH-Myrtleford. Six *TasOak* and six *E.ni16* 5-ply panels (300mm x 300mm) were pressed and glue bonds assessed (at Hexion laboratories, Figure 38 & Figure 39)

Figure 38: Cold pressing 300x300 *E.ni16* panels

Figure 39: Glue-bond test on *E.ni16* test panel

Practically all samples failed to produce an A-bond – with all but one sample (for each species) failing. Increases in hot press time did not improve the result. Although moisture content was within acceptable limits (<7%), a sample was redried down to 3%. However, there was no resultant improvement in bond quality. The results from the Hexion tests appeared to support the poor results previously observed with commercial plywood trials using *TasOak*. Commercial pressing trials were still scheduled at CHH-Myrtleford to provide clarity on results from a controlled commercial trial.

Bending test – machine configuration

MoE / MoR testing was carried out at UTAS structural testing facilities (Figure 40 and Figure 41).

Figure 40: Set up four poing bending test machine

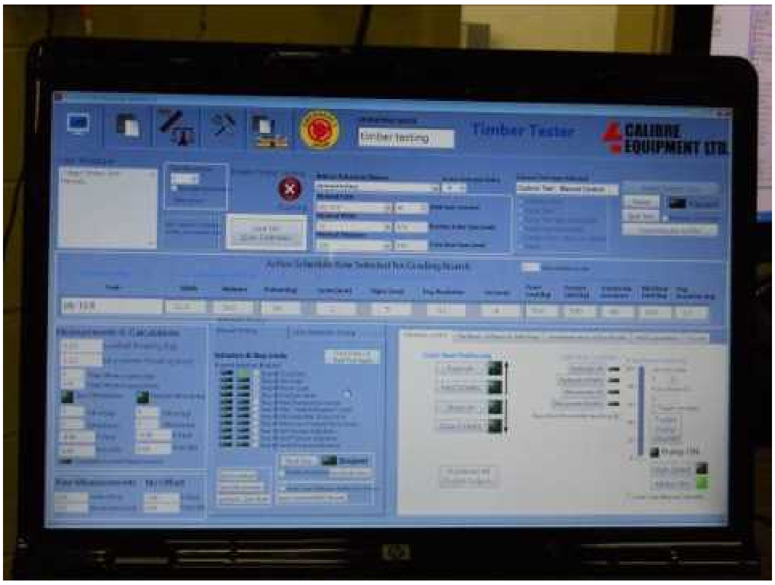


Figure 41: Control software of four point bending machine STFE^{TM} 10

MoR and MoE were determined according to AS/NZS 2269.1. Three bending sample pieces per panel, parallel (885 x 300 mm) and perpendicular (300 x 885 mm) to the face grain were taken for each panel. Machine configuration is shown in Figure 42.

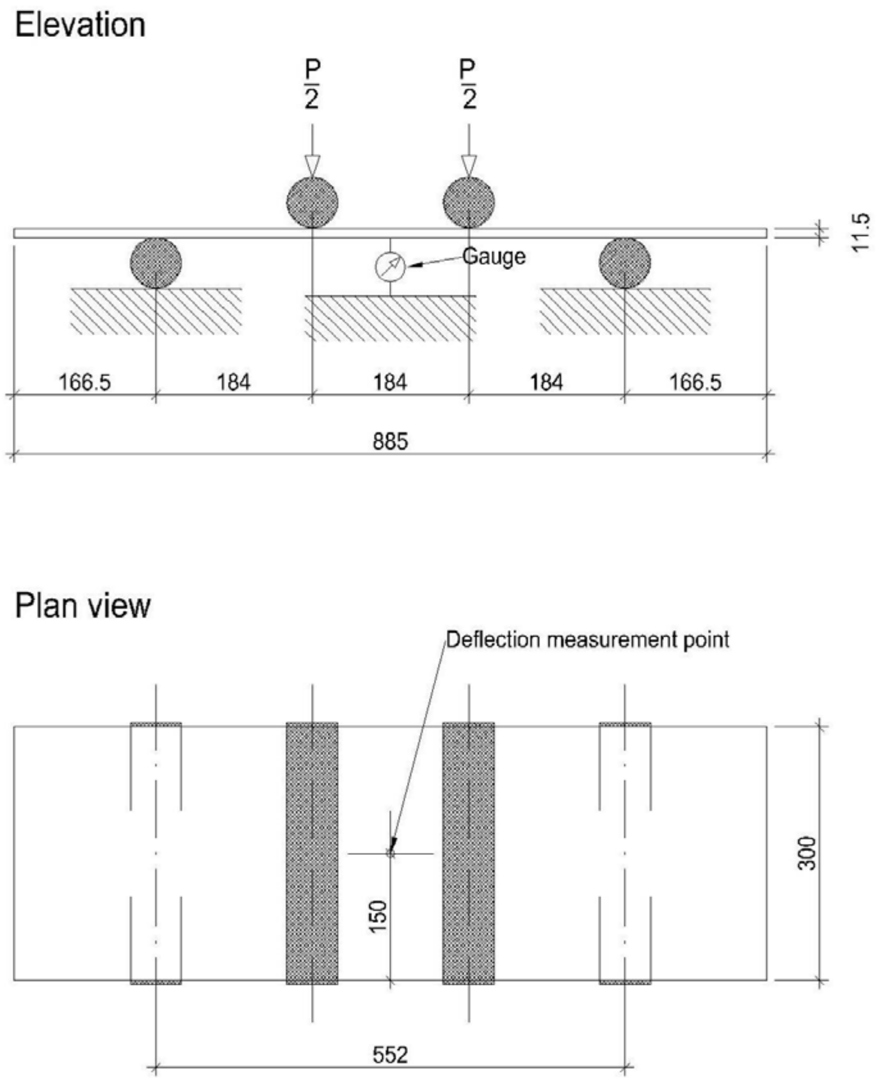


Figure 42: MoR and MoE machine test configuration

Modulus of elasticity (MoE)

The modulus of elasticity was tested with four point bending test configuration shown in Figure 42. Due to the same quality of surface veneers, plywood face orientation was random. Actual thickness was recorded and the deflection of the test piece was measured during the initial stage of the bending test with a gauge placed under the panel. The test piece was supported by rollers to achieve a free support condition. Load was applied at the third points of the span by the loading head. The gauge was removed when sufficient load-deflection curve was achieved to determine the gradient of the straight line portion of the curve to determine MoE. The gradient of this line was used to calculate the MoE applying Equation 5. For each test piece parallel to the face grain, the second moment of area (Equation 6 and Figure 43) was calculated according to AS/NZS 2269.0 and used for the calculation of MoE. The second moment of area of pieces tested perpendicular to the face grain was calculated with Equation 7 (Figure 44). The MoE values were then evaluated in accordance with AS/NZS 4063.2 to determine the characteristic values for the plywood samples.

Equation 5: Modulus of elasticity (AS/NZS 2269.1 2008)

$$E = \frac{23\,L^3}{1296\,I_{par.}}\left(\frac{P'}{\Delta}\right)$$

Where

E =	modulus of elasticity [GPa]
L =	test span [mm]
P'/Δ =	gradient of the load-deflection curve over the linear portion [N/mm]
$I_{par.}$ =	second moment of area for stiffness using parallel plies only [mm^4]

Equation 6: Second moment of area for calculation of bending rigidity for plywood with face grain parallel to span (AS/NZS 2269.0 2008)

$$I_{par.} = 2\left(\frac{1}{12}\,b\,d_1^3 + d_1\,b\,\bar{y}_1^2\right) + 2*0.03\left(\frac{1}{12}b\,d_2^3 + d_2\,b\,\bar{y}_2^2\right) + \frac{1}{12}b\,d_3^3$$

Where

d =	thickness of sheet [mm]
$\bar{y}$ =	distance from neutral axis [mm]
0.03 =	factor applied for plies at right angles to span

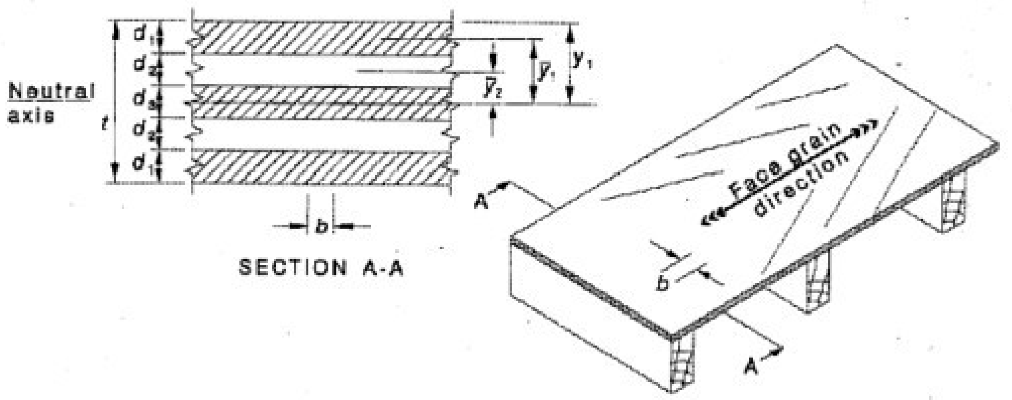


Figure 43: Calculation method for face grain parallel to span (AS/NZS 2269.0 2008)

Equation 7: Second moment of area for calculation of bending rigidity for plywood with face grain perpendicular to span (AS/NZS 2269.0 2008)

$$I_{par.} = 2*0.03\left(\frac{1}{12}\,b\,d_1^3 + d_1\,b\,\bar{y}_1^2\right) + 2\left(\frac{1}{12}b\,d_2^3 + d_2\,b\,\bar{y}_2^2\right) + 0.03\,\frac{1}{12}b\,d_3^3$$

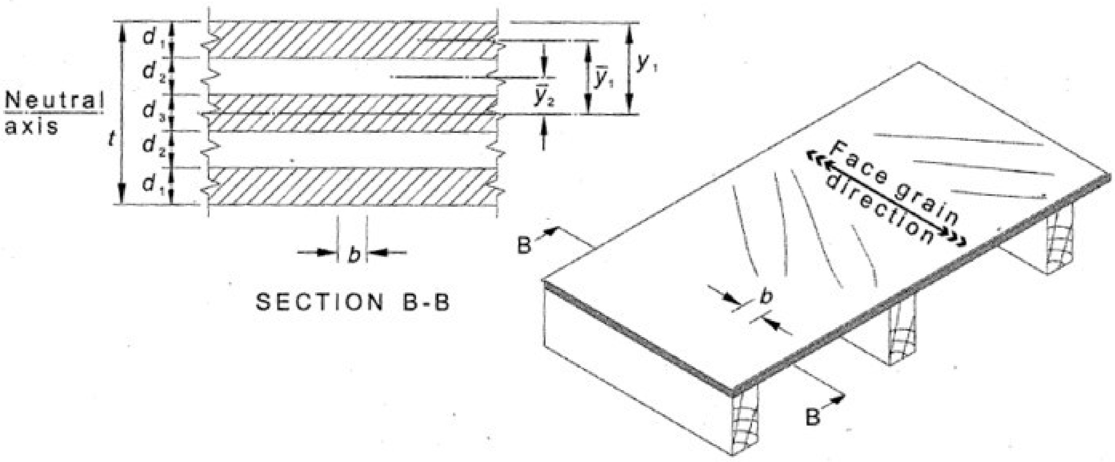


Figure 44: Calculation method for face grain perpendicular to span (AS/NZS 2269.0 2008)

Modulus of rupture (MoR)

After recording the load-deflection values for MoE each piece was tested with the same set up (Figure 42) for MoR, according to AS/NZS 2269.1. The rate of load application was adjusted such that failure of the test piece occurred within 3 to 5 minutes. The failure load was recorded and used in the calculation of MoR (Equation 8 and Equation 9). The sample values of MoR were evaluated in accordance with AS/NZS 2269.2 and AS/NZS 4063 to determine the characteristic value for each different resource.

Equation 8: Modulus of rupture (AS/NZS 2269.1 2008)

$$R = \frac{P_{\max} * L}{6 * Z_{par.}}$$

Where

R = modulus of rupture [MPa]

$P_{max.}$ = maximum load [N]

$Z_{par.}$ = section modulus [mm^3]

Equation 9: Section modulus (AS/NZS 2269.0 2008)

$$Z_{par.} = \frac{I_{par.}}{\bar{y}}$$

Shear strength

Two sample pieces (200 x 85 mm) per panel were tested in accordance to AS/NZS 2269.1 parallel and perpendicular to the face grain as shown in Figure 45. Eight holes per piece were cut with the CNC router. Panel length and thickness were manually measured with calipers and recorded. The test sample was then bolted on four 10 mm thick steel load-rails and tested with the UTAS structural test-rig.

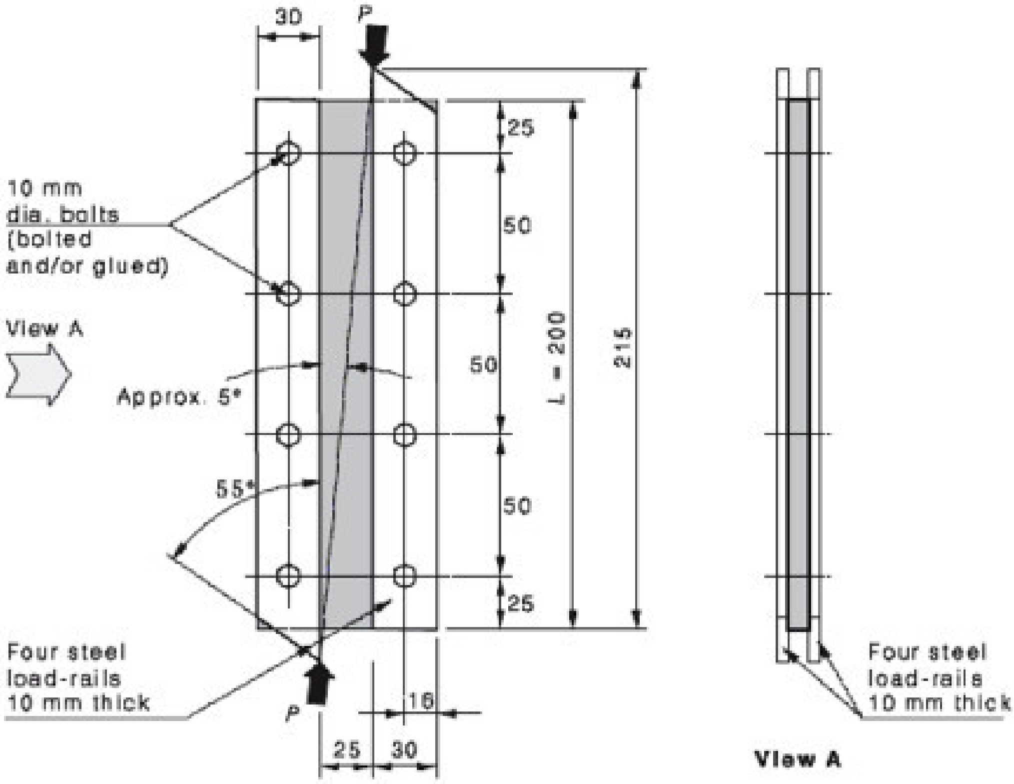


Figure 45: Panel shear strength test configuration (AS/NZS 2269.1 2008)

Shear test machine configuration is shown in Figure 46, Figure 47 and Figure 48. The failure load (maximum load) was recorded with an accuracy of 0.5 % and used in the calculation for shear strength (Equation 10). The characteristic shear values were determined by calculating the mean of both test pieces in each direction in accordance with AS/NZS 2269.2 and AS/NZS 4063.

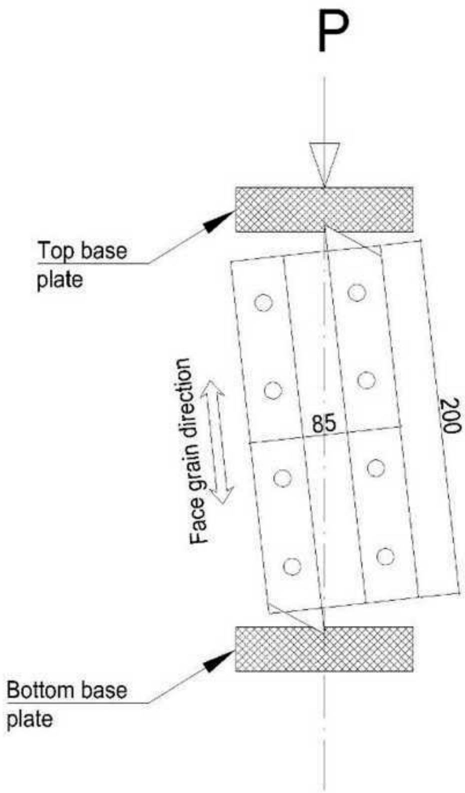


Figure 46: Panel shear strength test configuration along the grain

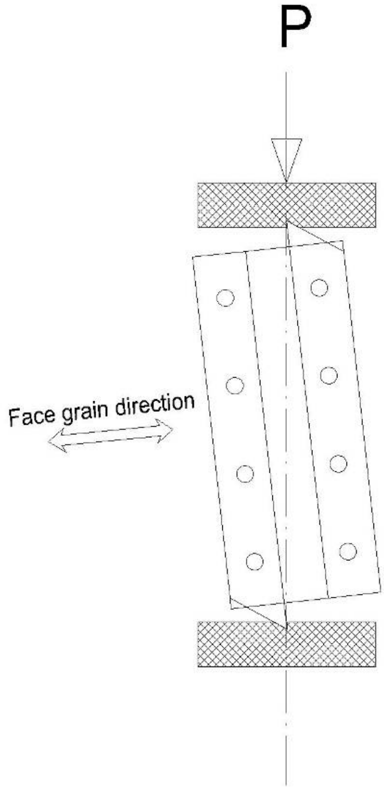


Figure 47: Panel shear strength test configuration perpendicular the grain

Equation 10: Panel shear strength (AS/NZS 2269.1 2008)

$$PS = \frac{P_{\max.}}{L * t}$$

Where
PS = panel shear strength [MPa]
L = actual length of test piece [mm]
t = overall thickness of plywood test piece [mm]

After shear testing, MC was determined using the oven dry method (AS/NZS 2098.1). Equation 11 was used to calculate the plywood MC.

Equation 11: Moisture content (AS/NZS 2098.1 2006)

$$MC = \frac{m_i - m_o}{m_o} * 100$$

Where
MC = moisture content [%]
m_i = initial mass of the test piece [g]
m_o = oven-dried mass of the test piece [g]

Figure 48: Shear test machine set up

Janka hardness

Hardness of timber and wood products indicates its ability to resist indentation. Three test pieces from each sample were tested for Janka hardness at two points for each piece. The tested piece was 150 x 50 mm and was selected randomly from the panel. The Janka hardness is determined with a test ball with 11.28 mm in diameter (Figure 49) that penetrates to a depth of 5.64 mm. The load is applied continuously at a rate of 6.5 mm per minute. Janka hardness was measured with a universal testing machine (Instron, Model 4206), load cell accuracy of 0.5 N and depth measurement accuracy of 0.0001 mm.

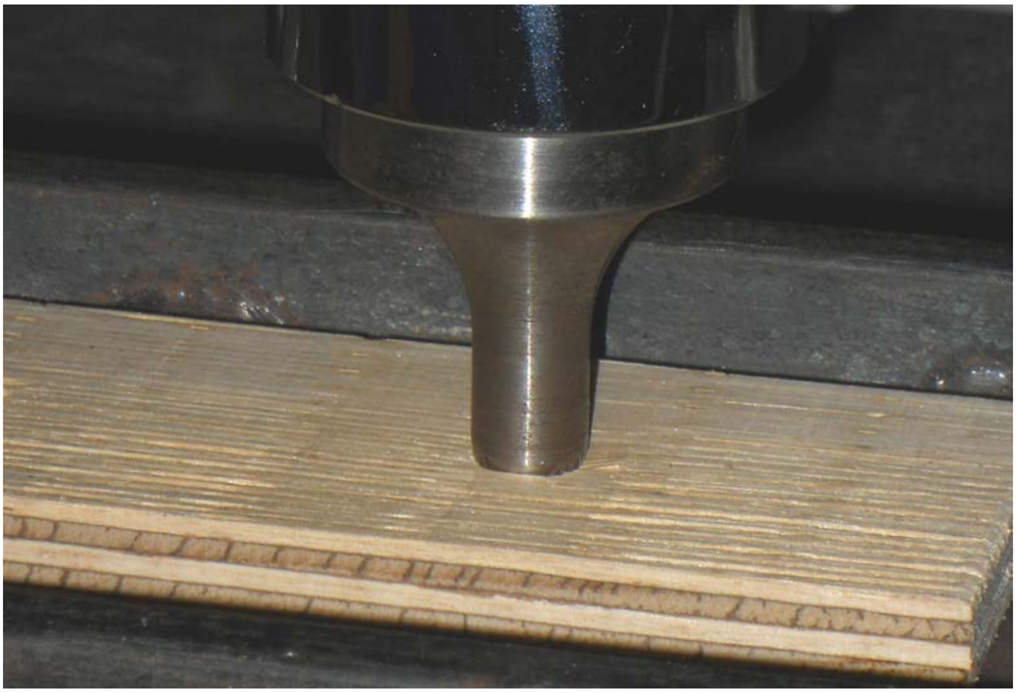


Figure 49: Janka hardness testing head with a plywood piece

Structural property evaluation

Characteristic values

Characteristic values were calculated from test results (sample size permitting) to estimate structural properties for each of the resources tested. Characteristic values calculated according to AS/NZS 2269.2:2007 is valid for sample size $n \geq 30$. Where $n \leq 30$, Equation 12 and Equation 13 was used to calculate the confidence coefficient factor (k_s) as shown in Table 7. Equation 12 is only valid for a sample size $n \geq 10$. For sample numbers less than 10 mean and standard deviation are shown.

Equation 12: Calculation of factor k_s, to calculate a one-tailed test of a normal distribution (Graf et al. 1987)

$$k_s = \frac{2(n-1)}{2(n-1) - u_{1-\alpha}^2} \times \left(u_{1-y} + u_{1-\alpha} \sqrt{\frac{2(n-1) + n \times u_{1-y}^2 - u_{1-\alpha}^2}{2n(n-1)}} \right)$$

Where
k_s = Confidence coefficient factor, when standard deviation is unknown
n = Number of sample size
u_{1-y} = Bound of standard normal distribution for a definite sampling rate y
$u_{1-\alpha}$ = Bound of standard normal distribution for a definite level of significance α

Equation 13: Calculation of factor $k_{s,□}$, to calculate a one-tailed test of a normal distribution (Graf et al. 1987)

$$k_{s,\sigma} = u_{1-y} + u_{1-\alpha} \times \frac{1}{\sqrt{n}}$$

Where
$k_{s,\sigma}$ = Confidence coefficient factor, when standard deviation is known

Table 7: K_S for one-tailed confidence level of a normal distribution

number of specimen [n]	1- α = 99%		1-□α = 95%		1-□α = 90%		1-□α = 75%	
	k_S	$k_{S,\sigma}$	k_S	$k_{S,\sigma}$	k_S	$k_{S,\sigma}$	k_S	$k_{S,\sigma}$
10	3.91	2.38	2.88	2.17	2.50	2.05	2.03	1.86
13	3.37	2.29	2.64	2.10	2.36	2.00	1.98	1.83
15	3.16	2.25	2.54	2.07	2.29	1.98	1.95	1.82
24	2.68	2.12	2.30	1.98	2.12	1.91	1.88	1.78
30	2.53	2.07	2.21	1.95	2.06	1.88	1.85	1.77
100	2.06	1.88	1.92	1.81	1.86	1.77	1.75	1.71
∞	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65

Genetic analysis

E.ni16

For DBH, assessed on all trees within replicates, the following linear mixed model was fitted in ASReml (Gilmour et al. 2006) to perform univariate restricted maximum likelihood analyses:

Y = MEAN + REP + RACE + *IBLOCK(REP)* + *PLOT(IBLOCK)+FAMILY(RACE)* + *RESIDUAL*

where; Y is the observation, MEAN is the mean, REP is the fixed replicate effect, RACE is the fixed race effect, *IBLOCK(REP)* is the random incomplete block within replicate effect, *PLOT(IBLOCK)* is the random plot within incomplete block effect, *FAMILY(RACE)* is the random family within race effect and *RESIDUAL* is the residual. As trees selected for the RPV trial represented a small sub-set of the entire progeny trial, terms for *IBLOCK(REP)* and *PLOT(IBLOCK)* were omitted from the analysis of all AWV and wood property traits.

To estimate genetic parameters for traits measured in the trees from the 16-year-old trial, a series of trivariate analyses were undertaken including DBH, stem straightness and the trait for which parameters were being estimated. Although its genetic parameters were not estimated, stem straightness was included in the analysis as trees for the RPV study were selected on their straightness. Trivariate analyses were undertaken instead of univariate analyses in an effort to account for possible bias introduced through the selection of stems suitable for RPV. It was not possible to fit multivariate models including more than three traits due to convergence difficulties. In the trivariate model, plot and incomplete block terms were fitted for DBH and stem straightness only.

The additive variance (σ^2_{add}), phenotypic variance (σ^2_{pheno}), open-pollinated narrow-sense heritability (h^2_{op}) and percentage coefficient of additive variation (CV_{add} %) were estimated for each trait as follows:

$$\hat{\sigma}^2_{\text{add}} = \frac{\hat{\sigma}^2_{\text{fam}}}{r}$$

$$\hat{\sigma}^2_{\text{pheno}} = \hat{\sigma}^2_{\text{fam}} + \hat{\sigma}^2_{\text{residual}}$$

$$\hat{h}^2_{\text{op}} = \frac{\hat{\sigma}^2_{\text{add}}}{\hat{\sigma}^2_{\text{pheno}}}$$

$$\text{C}\hat{\text{V}}_{\text{add}\,\%} = 100 \text{ x } \frac{\sqrt{\hat{\sigma}^2_{\text{add}}}}{\bar{x}}$$

where σ^2_{fam} , σ^2_{plot} and $\sigma^2_{\text{residual}}$ are the variance components for *FAMILY(RACE)*, *PLOT(IBLOCK)* and *RESIDUAL* respectively, *r* is the coefficient of relationship among individuals within open-pollinated families, set at 0.4 to account for an assumed selfing rate in open-pollinated families of 30% (Griffin and Cotterill 1988), and $\bar{x}$ is the mean. The significance of the family variance was tested using a 'one-tailed' likelihood ratio test (Self and Liang 1987). The significance of the RACE term for each trait was gauged with a Wald F-test, where *FAMILY(RACE)* was the error term and the approximate denominator degrees of freedom were computed using the numerical method (Gilmour *et al.* 2009).

Bivariate analyses were undertaken to estimate pair-wise covariances among random terms. Additive genetic correlations (r_a) were estimated according to the following function:

$$r_{g_{12}} = r_{fam_{12}} = \frac{\hat{\sigma}_{\mathrm{fam}_{12}}}{\sqrt{\hat{\sigma}^2_{\mathrm{fam}_1}\hat{\sigma}^2_{\mathrm{fam}_2}}}$$

where $r_{fam_{12}}$ is the *FAMILY(RACE)* correlation between traits 1 and 2, $\hat{\sigma}_{\mathrm{fam}_{12}}$ is the *FAMILY(RACE)* covariance component between traits 1 and 2 and $\hat{\sigma}^2_{\mathrm{fam}_1}$ and $\hat{\sigma}^2_{\mathrm{fam}_2}$ are the *FAMILY(RACE)* variances for traits 1 and 2 respectively. Significance tests of inter-trait genetic correlations against zero were conducted using a 'two-tailed' likelihood ratio test and against one or minus one, as appropriate, using a 'one-tailed' likelihood ratio test (Gilmour et al. 2006). Inter-trait phenotypic Pearson's correlations were estimated and two tailed t-tests were used to test if phenotypic correlations were significantly different from zero.

E.ni26* and *E.glob

For the traits of; basic density, standing tree AWV, log AWV, billet AWV, outer veneer sheet dynamic MoE, NIR Kraft pulp yield and NIR Cellulose of the study trees, the following linear mixed model was fitted using the Mixed Models (REML) function in Genstat 13th Edition to perform univariate restricted maximum likelihood analyses:

Y = MEAN + GROUP + *RESIDUAL*

where; Y is the observation (trait), MEAN is the mean, GROUP is the fixed family effect in the *E.ni26* trial or fixed provenance effect in the *E.glob* trial, and *RESIDUAL* is the residual.

Results & Discussion

Tree & Log Characteristics

Prior to discussion of results it is important to recall that the primary objectives of this research relate to the un-thinned / unpruned *E.ni16* resource – representative of the significant increases in volume forecast by Forestry Tasmania for this resource within the short-term (1-5yrs). The primary objectives are to assess:

1) Market potential for veneer and plywood manufactured from *E.ni16* through characterization of log processing and product properties.
2) Estimate the genetic parameters of traits affecting *E. nitens* RPV veneer quality and their genetic and phenotypic correlations with traits important to existing fibre crop breeding objectives.

The *E.ni26* resource is of secondary importance and is relevant in the longer term according to pruned / thinned plantations that will be managed on longer term rotations (20-25yrs) by Forestry Tasmania. The upper logs of this resource may be suitable for peeling applications. The *E.glob* resource is likely beyond commercial rotation age but was included to garner peeling related quality data and for genetic analysis. The *TasOak* resource was included to provide a reference to the native-forest regrowth material currently processed in Tasmania.

In light of the research objectives, differences between resources need to be considered in the context of site quality, genetic variation and log position and shouldn't be simplified to age or species effects alone. Table 8 shows the tree, resultant log and billet characteristics with sample numbers for each resource.

Table 8: Tree, log and billet characterisitcs

	Species	*E. nitens*		*E. nitens*		*E. globulus*		*TasOak*	
	Harvest Age	16		26		33		*	
	Site	Tarraleah		Dial Range		Lisle		Southern Tasmania	
	Number of Trees	534		50		24		13 billets	
Trees	Selection Details	3-5 trees x 110 Families		5 trees x 10 Families		4-5 trees x 5 Provenances		Random Logyard Selection	
Trees	Silviculture	UT / UP		UT / UP		Thinned (400 stems/ha) UP		*	
Trees	Planting Year	1993		1984		1977		*	
Trees	Stocking Density [stems/ha]	1300		1100		1600		*	
Trees	Log Position	Butt-log		2nd Log		2nd Log		*	
Trees		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Trees	DBH Over Bark [cm]	28	3	40	4	35	3	*	*
Long Logs	Small End Diameter [mm]	*	*	294	34	240	31	*	*
Long Logs	Large End Diameter [mm]	*	*	324	37	269	31	*	*
Long Logs	Length [m]	5.21	0.17	4.32	0.20	5.81	0.29	*	*
Long Logs	Basic Density [kg/m^3]	471	27	520	41	600	40	*	*
Long Logs	Green Density [kg/m^3]	973	58	1065	34	1099	30	*	*
Long Logs	Green Moisture Content [%]	51.5	3.4	51.2	2.9	45.4	2.6	*	*
Long Logs	Predicted Kraft Pulp Yield [m^3/ha]	52.1[a]	1.2[a]	55.5	1.4	57.6	2.6	*	*
Long Logs	Extractive Content [%]	4.02[a]	0.69[a]	2.87	0.69	2.74	1.40	*	*
Long Logs	Number of Logs	534	*	50	*	24	*	*	*
Billets	Small End Diameter [mm]	231	33	303	37	259	30	383	109
Billets	Large End Diameter [mm]	250	34	326	39	272	30	414	110
Billets	Length [m]	2.62	0.01	2.61	0.01	2.62	0.00	2.62	0.02
Billets	Number of Logs	497	*	50	*	24	*	13^	*

Notes: [a] Based on 495 samples
^ Billets
* No data available

From the three plantation resources, trees (and resultant billets) were largest from the *E.ni26*, followed by the *E.glob* and *E.ni16*. Density was highest in the *E.glob* logs followed by *E.ni26* and *E.ni16*. Observed basic densities are within the range of published figures considering species and age class (see Farrell et al. 2010 for a review of published figures). Average basic density for *E.ni16* is below the 520 kg/m^3 figure suggested as the minimum for satisfactory face veneers (McMillan, 1978). The *E.ni26* resource attains this suggested minimum level for basic density (but is still considered low) whilst the *E.glob* basic density is higher (600 kg/m^3). TasOak density is usually between 600 and 700+ kg/m^3(pers.comm D. Ridley).

Extractive content was highest in the *E.ni16*, whilst similar levels were observed in the *E.ni26* and *E.glob*. The statistically significant ($P<0.001$) higher extractive content in *E.ni16* may be attributable to rate of growth. Selection of trees from this stand was biased towards the larger diameter material (i.e. faster growing trees) in an attempt to meet minimum diameter processing requirements. As reviewed by Armstrong 2003, extractive content is generally considered positively correlated with rate of growth.

Veneer Properties

Dimensions

Table 9 shows the veneer properties from the four different resources. It should be noted that the *E.ni16* and *TasOak* values are based on data obtained from the Metriguard veneer grader, whilst the *E.ni26* and *E.glob* values are based on manual veneer assessment. This manual method used 3 sample points for each sheet, compared to the Metriguard method which takes multiple measurements along a sheet. Veneer thickness is an important quality consideration due to the impact on glue application and therefore glue-bonding, and to meet requirements of relevant standards for finished products e.g. AS2269. Considering average dry thickness, all plantation material is within the permissible range (according to current production standards) for a 2.4mm nominal product. The average thickness of 2.72mm observed for the regrowth material is likely due to an operator error during lathe set-up prior to the trial production run. Normal green target thickness is 2.65mm for *TasOak*. The target green thickness for the plantation species was 2.6mm. Considering published radial shrinkage values (approximate figures; *E.ni* 5%, *E.glob* 7%), observations for the plantation material are as expected assuming target green thickness was achieved (green dimensions were not assessed).

Table 9: Veneer properties

	Species	*E. nitens*[1]		*E. nitens*[2]		*E. globulus*[2]		*TasOak*[1]	
	Harvest Age	16		26		33		*	
	Site	Tarraleah		Dial Range		Lisle		Southern Tasmania	
Veneer		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
	Number of Billets Peeled	452	*	49	*	18	*	13	*
	Thickness [mm]	2.51	0.11	2.47	0.07	2.42	0.07	2.72[a]	0.04
	Width [mm]	1320	21	1291	34	1263	21	1282	30
	Length [mm]	2531	*	2531	2	2531	2	2531	*
	Recovery of Long Grain Veneer [%]	35	12	50	8	35	9	53	17
	Total Number of Long Grain Sheets	2488	*	631	*	121	*	266	*
	Long Grain Sheets / Billet	6	*	13	*	7	*	20	*
	Visual Grade A [%]	0	*	0	*	0	*	2	*
	Visual Grade B [%]	0	*	0	*	0	*	0	*
	Visual Grade C [%]	0	*	0	*	3	*	2	*
	Visual Grade D [%]	49	*	58	*	96	*	41	*
	Total Visual Grade Pass [%]	49	*	58	*	99	*	45	*
	Total Visual Grade Failure [%]	51	*	42	*	1	*	55	*
	Dry Moisture Content [%]	2.5[b]	1.5	5.2[c]	*	5.7[c]	*	4.2[b]	1.8
	Density$_{12\%MC}$ [kg/m^3]	511	33	643	69	794	64	601	91
	Velocity UPT [m/s]	4533	306	5668	301	6078	306	5099	391
	MoE$_{dyn}$ [GPa]	10.5	1.5	19.6	3.7	27.9	4.3	15.9	3.3

Notes
[1] Values based on Metriguard data
[2] Values based on manual assesment data
[a] High thickness value likely attributed to operator error during set-up at lathe
[b] Moisture content data from Metriguard radio frequency sensors
[c] Moisture content data from hand-held capacitance type moisture meter
[*] No data available

With regard to sheet width we can be confident that equal width was achieved due to the automated control of the sheet clipping process. Consequently, we can compare the average tangential shrinkage for the different resources. Shrinkage was lowest in the *E.ni* (16yr 9.0%, 26yr 11.0%) followed by *TasOak* (11.6%), with *E.glob* exhibiting greatest tangential shrinkage (12.9%). This trend is in line with published shrinkage figures for these species.

Grades & Recovery

Recovery of long-grain sheets (based on measured dry dimensions - Table 8) was highest for the regrowth material and the *E.ni26* (53% and 50% respectively). 35% recovery was observed for both *E.ni16* and the *E.glob* material. Total recovery of long-grain sheets in commercial peeling operations is in the region of 40-55%, of which at least 80% would attain visual grade D. Only 45% of the *TasOak* resource attained visual grading standards. The low recovery is attributed to defects associated with large knots and resin pockets in the sampled regrowth billets. Consequently, the small mill-run sample of regrowth billets obtained in this trial would not be considered representative of average production and is a result of high degree of variation inherent to native regrowth logs.

Long-grain recoveries from TasOak are in the order of 47% with 33% A/B, 33% C and 33% D grade (pers. comm. D Ridley). The veneer that doesn’t make long grain makes short grain. This study did not segregate veneer into LG and SG, which is the normal practice. However, LG was needed to make the ply sheets. Indeed, the unpruned plantation veneer would have all gone to SG. This is illustrated by Figure 51 Veneer Grade F, which says it is ‘out of grade’.

With regards long-grain recovery the *E.ni26* resource looks promising, albeit with only 58% of the material attaining visual grade D. The question remains however, if the material that fails the current visual grade standard is still fit for use in terms of its structural properties (i.e. can be used for internal layers or in products with less demanding aesthetic requirements). Both the *E.glob* and *E.ni16* material are well below commercial requirements in terms of long-grain recovery.

The low recovery from the thirty-three yr old *E.glob* trees is likely attributable to the small billet diameters relative to the *E.ni26* (attributed to poorer site conditions). However, relative to the diameters for the *E.ni16*, it would have been reasonable to expect a higher recovery value. Log eccentricity or sweep may have attributed to the recovery result as the high grade recovery (99%) of sheets attaining at least visual grade D indicates minimal degrade in recovered sheets. The better self-pruning qualities of *E.glob* relative to *E.ni* may have also contributed to this result.

Figure 50: Veneer grade D (in standard)

Figure 51: Veneer grade F (out of standard)

For comparison with relevant published figures McKimm (1986), recorded 40% recovery for dry, trimmed long-grain sheets peeled from 20yr old *E.ni*. However, minimum core diameter was 160mm compared to 65mm in this study and logs were steamed prior to peeling. Thomas *et al* 2009 peeled (steamed) 34 yr old logs from five Eucalypt species (*E. agglomerata, E. dunnii, E. grandis, E. pilularis, E. saligna*) and observed (total) green off-lathe recoveries in the region of 30-45%. Younger *E. dunnii* (12 and 17 yr old) peeled in the same study produced similar recoveries.

Moisture content

The target moisture content for veneer dried at the TaAnn mill was 6-8%. In practice, veneer is often dried below the 6% target to minimize potential gluing problems associated with moisture contents higher than 8% (if an A-bond is to be achieved with phenol-formaldehyde type glue). The MC of the *E.ni16* was very low at (2.5%), however, such low MC's are not necessarily unusual in manufacture of veneer based products (pers. Comm. Simon Dorries, EWPAA, Dec 2010). Due to the faster drying nature of *E.ni* (relative to *TasOak*) the dryer throughput speed was increased in an attempt to reduce over-drying. However, the standard *TasOak* schedule was used (of necessity) to minimize interruption to commercial operation. The *E.ni26* and *E.glob* were graded and assessed manually (rather than via automated Metriguard veneer grader) at a later date, and thus it is reasonable to assume that the MC for these species (5.2% and 5.7% respectively) would have been lower had the material been assessed closer to the time of drying. It is noted that *E.glob* is generally slower to dry relative to *E.ni*.

Significant deterioration in post-drying veneer quality was observed through the course of the project work. Sheets from the plantation resource were generally fragile and difficult to handle (relative to the *TasOak* control material) with numerous splits and checks. Sheets from the *E.ni* resource tended to be more fragile than the *E.glob* resource, possibly related to greater levels of splitting and lower sheet density. A schedule developed specifically for the plantation resource would likely provide gains in resultant veneer quality. Furthermore, segregation of green veneer according to moisture content (e.g. sap, sap/heartwood and heartwood) and drying these classes in appropriate conditions would likely improve MC consistency and veneer quality. The development of optimised drying schedules for plantation material is discussed further in section 5.4 (recommendations for future work).

Density

Veneer sheet density for each resource follows the trend for basic density observed from the wood properties disc (Table 9). Density is highest for the *E.glob*, followed by *E.ni26* and lowest in *E.ni16*. Basic density was discussed under Tree & Log Characteristics (section 4.1), however as there were no basic density values (obtained from log-disc samples) for regrowth logs we note the dry density figure for this resource as measured by the metriguard veneer grader (601kg/m^3). The observed density of the regrowth logs acquired in this research is in the lower range of expected values for this resource (pers. Comm. David Ridley, TaAnn, Dec 2010). The normal density range found at TaAnn is within 600 and 700+ kg/m^3.

Dynamic MoE

MoE is an important veneer quality property for structural products indicating its stiffness or ability to resist distortion under load. Dynamic MoE (AWV^2 x density) is commonly used to rapidly assess stiffness-related properties and is widely used to pre-grade veneers for LVL production. The highest average veneer MoE_{dyn} (i.e. stiffest wood) was estimated for veneer peeled from upper logs of the *E.glob* (27.9 GPa) and *E.ni26* resources (19.6 GPa). The *TasOak* material had an average MoE_{dyn} of 15.9 GPa, whilst the lowest MoE_{dyn} was estimated for the *E.ni16* resource (10.5 GPa).

The focus of this work relates primarily to the *E.ni16* yr resource and thus we refer to the MoE requirements for F11 and F14 stress grade classification (AS/NZS 2269:0:2008), currently supplied by the radiata pine resource for reference purposes. The veneers were segregated into three stiffness classes low, <10.5 GPa (i.e. <F11), medium, 10.5-12 GPa (i.e. F11) and high > 12 GPa (i.e. F14). Using average stiffness on a family basis, 61% of the *E.ni16* families were classified as low stiffness failing to make an F11 equivalent, 37% was medium stiffness (F11 equivalent) and only 2% high stiffness (F14 equivalent). All *E.ni26* families produced “high stiffness” veneers. Data for the *E.glob* and *TasOak* resource was analysed at the tree level, with all the *E.glob* material classified as high stiffness and *TasOak* having 23% medium and 77% high stiffness.

Table 10: Summary table for families showing tree stiffness classes

	< 10.5 GPa [%]	10.5-12 GPa [%]	≥ 12 GPa [%]	MoE average [GPa]
***E. nitens* 16yr**[a]	61	37	2	10.5
***E. nitens* 26yr**[a]	0	0	100	19.6
***E. globulus* 33yr**[b]	0	0	100	27.9
TasOak[b]	0	23	77	15.9

Notes [a] Based on average MoE at family level
b Based on average MoE at tree level

Relevant research in New Zealand (Gaunt *et al* 2003) based on veneer peeled from the unpruned upper log from a pruned 15yr *E.ni* stand, produced veneer that was segregated into stiffness classes based on MoE_{dyn} for LVL production. Three classes were created in their study with percentage distribution as follows; low stiffness (< 15 GPa) 35%, medium stiffness (15-17 GPa) 35% and high stiffness (> 17GPa) 30%. All veneer from the butt-log *E.ni16* peeled in our trial would be categorized into the low stiffness class (and similar to values for *P. radiata*), whilst the majority of veneer produced from the upper logs of the *E.ni26* resource would fall into the high stiffness class, according to these categories. TasOak normally has values in the range 15 – 26 GPa, much higher than found in this study.

Plywood Properties

Table 11 details the observed properties for the plywood samples produced and tested from each resource and are discussed in the subsequent chapters.

Table 11: Plywood properties

	Species	*E. nitens*		*E. nitens*		*E. globulus*		*TasOak / E. ni16*		*TasOak / P.rad*	
	Harvest Age	16		26		33		*		*	
	Site	Tarraleah		Dial Range		Lisle		South TAS/Tarraleah		South TAS/ *	
Plywood		Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
	Number of Plywood Panels	30	*	30	*	13	*	2	*	10	*
	MoE$\|_{05[75]}$ (average) [GPa]	11.2 (11.8)[a]	2.2	20.1 (20.3)	1.8	27.4 (28.0)	3.5	15.4 (16.2)	1.5	16.1 (16.5)	2.0
	MoR$\|_{05[75]}$ (average) [MPa]	36 (55)[a]	12.5	64 (86)	13.0	100 (128)	15.5	(87)	7.9	62 (79)	10.0
	Shear$\|_{05[75]}$ (average) [MPa]	3.6 (4.4)[a]	0.42	4.4 (5.2)	0.46	5.1 (5.7)	0.31	(5.0)	0.23	*	*
	Janka Hardness [kN]	4.50[b]	0.53	6.75	0.99	8.49	0.63	4.90	0.24	*	*
	Glue bond pass rate press 1 [%]	73	*	*	*	*	*	*	*	100	*
	Glue bond pass rate press 2 [%]	13	*	100	*	100	*	100	*	*	*
	Thickness press 1 [mm]	12.14	0.21	*	*	*	*	*	*	11.80	0.20
	Thickness press 2 [mm]	11.55	0.26	11.48	0.18	11.60	0.27	11.10	0.65	*	*

Notes [a] Six samples removed due to glue-line failure attributed to high veneer MC
[b] Only samples from 2nd pressing tested for shear and hardness (n=15)
[*] Data not available

Processing characteristics

During the preparation of plywood testing samples, panels were processed to the required testing dimensions using a CNC router and circular saw. During this process significant splitting of the face grain was observed particularly for cuts perpendicular to the face grain in the *E.ni* panels (Figure 52). Such splitting might be avoided through improved veneer processing (log steaming and optimised drying) leading to reduced brittleness and general improvement in veneer quality.

Figure 52: Spliting observed during panel processing using CNC router (cut perpendicular to the face grain shown)

Thickness

Thickness was determined in accordance with AS/NZS 2098.2:2006. The tolerance for a nominal 12 mm panel is ±4 % (AS/NZS 2269.0 2008). On average the *E.ni16*, *E.glob* and *TasOak / P.rad* panels were within target whilst the *E.ni26* just failed to meet the tolerance level at 0.3 % under the minimum. Looking more closely at the *E.ni26* it was observed that 47 % of the panels achieved thickness requirements. The *TasOak / E.ni16* panels are (on average) 3.5 % below the minimum thickness. From a sample of two panels with this layup, one failed to meet minimum requirements whilst the other was within range (albeit at the low end). With regards to the resources that passed considering their average values, we observe that 100% and 47% of the *E.ni16* (first and second pressing respectively), 62% of the *E.glob* and 100% of the *TasOak / P.rad* panels were within tolerance. Generally, it is observed that all panels were close to the minimum thickness requirements (with the exception of the first pressing of *E.ni16*) therefore an increase in target green thickness for the peeled veneer could be considered. Peeling thickness can be optimised in due course through consideration of veneer shrinkage and density properties.

Glue-bond quality

Bond quality was determined in accordance with AS/NZS 2098.2-2006. Table 12 shows the pass rate and bond quality for the A-bond tests conducted by EWPAA. The first pressing trial consisted of 15 *E.ni16* panels, 10 *TasOak* / *P.rad* panels and 5 *P.rad* panels as a control. The second pressing trial consisted of 30 of *E.ni26* panels, 13 *E.glob* panels and 2 panels of *TasOak* / *E.ni16*.

Table 12: Glue-bond quality

	Pressing Trial 1 (11th Feb 2010)	Pressing Trial 2 (10th Jun 2010)	Number of samples	Pass Rate [%]	Bond quality value mean	std dev
E. nitens **16yr**[a]		●	15	13	4.03	1.10
E. nitens **16yr**	●		15	73	5.17	0.93
E. nitens **26yr**		●	30	100	7.35	1.01
E. globul**us 33yr**		●	13	100	7.46	1.05
TasOak / E.ni16		●	2	100	6.40	0.57
TasOak / P.rad	●		10	100	6.65	0.94
P. radiata	●		5	100	7.68	0.82

Notes [a] Glueline failure attributed to high veneer MC

With the exception of *E.ni16* all species achieved a pass rate of 100%. The samples of *E.ni16* from the first pressing trial had 27% failures (i.e. 4 out of 15 panels failed to meet A-bond requirements). The poor pass rate of only 13% from the second pressing trial is attributed to average veneer moisture content in the region of 8% (determined via hand-held capacitance type MC metre prior to pressing). We were unable to redry this veneer for the second pressing trial due to transport delays resulting in late delivery of material to the mill. It is anticipated that had this material been redried to a target 4-6% MC, glue-bonding results would likely have been similar to results from pressing trial one. Other contributing factors could be the knottiness of the material or the presence of reaction wood in the young stems. Overall, the glue-bond results look promising (relative to previous in-house trials on plantation hardwood) and further improvement in bond quality could be expected through improved veneer quality and optimisation of the pressing schedule and gluing parameters for each species. It is noted that in McKimm's study (1986) a minimum bond quality of 8 was achieved for the 20yr *E. nitens* trialled, according to AS 2098 (S.A.A. 1977). However it is unclear whether this refers to A-bond or B-bond tests with no reference being made to the gluing parameters used. A Chilean study pressing plywood from 11yr old *E. nitens* (Lisperguer & Rozas 2005) produced satisfactory results fulfilling British Standards Institute requirements for exterior use (BS 6566).

MoE

Three samples from each panel were tested for strength and stiffness properties, to ensure reliable results for each panel. However, due to the poor glue-bonding for the second pressing of *E.ni16* four panels were based on two samples / panel due to an extreme low value from the third. Additionally, six panels delaminated during MoE / MoR testing (exhibiting glue-line failure) and were excluded from the analysis reducing the sample number for *E.ni16* from 30 to 24.

Table 13 and Table 14 present the average and characteristic MoE and bending strength for each resource. Continuing the trend observed for veneer MoE_{dyn}, high stiffness properties were observed for the *E.glob* and *E.ni26* resources parallel to the face grain with characteristic stiffness of 27.4 GPa and 20.1 GPa (respectively). The characteristic MoE for the *E.ni16* was 11.2 GPa. Stress grades (F-ratings) are discussed in section 4.3.9, but based on these characteristic values for MoE the samples produced plywood with F-ratings of F34, F27 and F11 parallel to the face grain (for *E.glob*, *E.ni26* and *E.ni16* respectively).

Due to small sample numbers for the composite *TasOak* panels, characteristic values were not calculated. Considering the average values, the *TasOak* / *E.ni16* panels may attain F17 classification, whilst *TasOak* / *P.rad* panels could gain F22 classification (estimated from indicative average values).

Table 13: Characteristic bending stiffness (MoE) of plywood samples parallel and perpendicular to face grain.

	Number of specimens	E_k [GPa] ∥	E_k [GPa] ⊥
***E. nitens* 16yr[a]**	24	11.2	9.7
***E. nitens* 26yr**	30	20.1	19.0
***E. globulus* 33yr**	13	27.4	23.5
TasOak / E.ni16	2	15.4	14.0
TasOak / P.rad	10	16.1	10.8

Notes [a] Six samples removed due to glue-line failure and evident delamination during MoE / MoR testing

Table 14: Modulus of elasticity (MoE): Mean and standard deviation of plywood samples parallel and perpendicular to face grain.

	Number of specimens	MoE [GPa] ‖		MoE [GPa] ⊥	
		mean	std dev	mean	std dev
E. nitens **16yr**[a]	24	11.8	2.2	10.3	2.3
E. nitens **26yr**	30	20.3	1.8	19.3	2.1
E. globulus **33yr**	13	28.0	3.5	24.2	3.9
TasOak / E. ni16	2	16.2	1.5	14.7	1.5
TasOak / P.rad	10	16.5	2.0	11.3	2.3
P.rad	5	13.4	1.3	12.8	1.7

Notes [a] One sample removed due to glueline failure attributed to high veneer MC

The *E.ni16* panels were produced in two separate pressings. For the first pressing trial, selection and position of veneers was randomised. For the second pressing trial the stiffest veneers (i.e. those from the outside of the log) were used for the panel faces to optimise stiffness values. Selecting the stiffest veneers for the face sheets increased panel stiffness by 18% relative to the panels with randomly selected veneer layup (i.e. MoE of 13.0 GPa vs. 11.0 GPa). The mean stiffness for the two groups was significantly different ($\alpha = 0.05$). The two layups tested for the *E.ni16* panels are discussed further in section 4.3.10.1 (stiffness optimised panels from *E.ni16*).

Bending MoR

As discussed above, 6 panels (from 30) of the *E.ni16* revealed delamination during MoE / MoR testing, failing in shear (Figure 53) during testing as opposed to the expected fracture, i.e. failure in bending, as shown in Figure 54. All samples with a MoR failure in shear also featured a very poor glue-bond result, and as per MoE results these samples were excluded from the MoR analysis.

Figure 53: Failure in shear

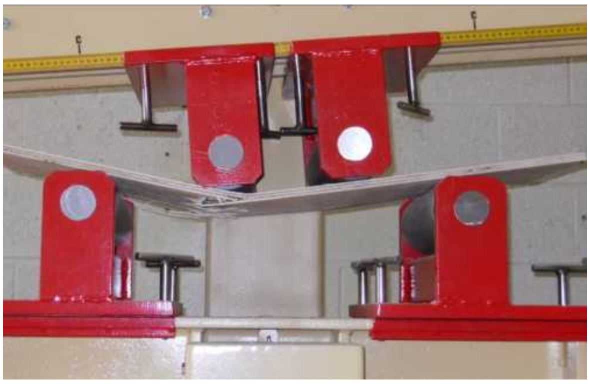


Figure 54: Failure in bending

Table 15 presents the characteristic bending strength values calculated for each resource. The trend for MoR follows that observed for MoE. *E.glob* has the highest characteristic bending strength, 100 MPa (parallel to face grain) attaining stress grade F34, followed by *E.ni26* (63.8 MPa, F17), *TasOak* / Pine (62.0 MPa, F17) and *E.ni16* (36.4 MPa, F11).

Table 15: Characteristic bending strength of plywood samples parallel and perpendicular to the face grain.

	Number of specimens	f'b [MPa] ‖	f'b [MPa] ⊥
E. nitens 16yr[a]	24	36.4	34.7
E. nitens 26yr	30	63.8	60.3
E. globulus 33yr	13	100.0	84.0
TasOak / P.rad	10	62.0	31.0

Notes [a] 6 samples removed due to glue-line failure attributed to high veneer MC

As characteristic values were not calculated for samples sample sizes smaller than ten, Table 16 provides the average MoR figures for all resources. It is observed that the *TasOak / E.ni16* panels are stronger than the *TasOak / P.rad* in both directions (11% parallel to face, 5% perpendicular to face grain).

Table 16: Modulus of rupture (MoR): Mean and standard deviation of plywood samples parallel and perpendicular to the face grain.

	Number of specimens	MoR [MPa] ‖ mean	MoR [MPa] ‖ std dev	MoR [MPa] ⊥ mean	MoR [MPa] ⊥ std dev
E. nitens 16yr[a]	24	55.4	12.5	56.3	13.2
E. nitens 26yr	30	85.7	13.0	92.4	18.4
E. globulus 33yr	13	128.2	15.5	124.2	22.8
TasOak / E.ni16	2	87.4	7.9	69.3	2.0
TasOak / P.rad	10	79.0	10.0	66.0	23.0
P. radiata	5	67.0	17.5	66.0	21.0

Notes [a] 6 samples removed due to glue-line failure attributed to high veneer MC

Shear strength

Due to loss of panel samples at the mill, shear (and Janka hardness) were not assessed for the first pressing of *E.ni16* and the *TasOak / P.rad* panels. All tested samples displayed a true shear failure between the rails (Figure 55 to Figure 58).

Figure 55: Shear failure parallel to the face grain (*E.ni26*)

Figure 56: Shear failure parallel to the face grain with marked lines (before testing) perpendicular to the tested direction (*E.ni16*)

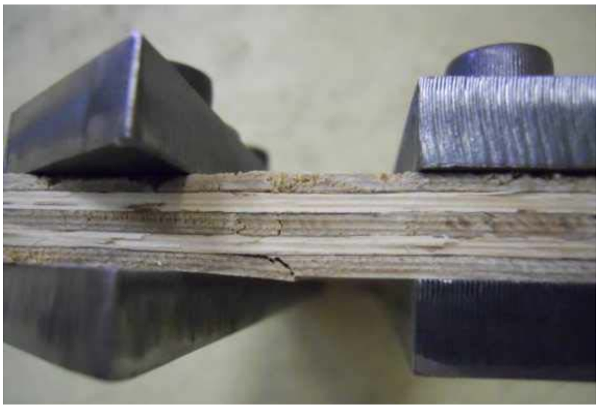


Figure 57: Shear failure in panel cross-section (*E.glob*)

Figure 58: Panel displacement after shear test perpendicular to the face grain with marked lines (before testing) perpendicular to the tested direction (*E.glob*)

A t-test (unpaired, α = 0.95) was used to compare *E.ni16* samples with a failure in glue-bond quality and those with a sufficient glue-bond result, revealing no significant difference in shear strength associated with glue-bond quality. Table 17 and Table 18 show the mean and characteristic shear strength values for each resource. The shear results follow the trends observed for MoE and MoR where *E.glob* exhibited the highest strength parallel to the face grain with a mean shear value of 5.67 MPa, followed by *E.ni26* (5.21 MPa), *TasOak / E.ni16* (4.99 MPa) and again the lowest strength observed for *E.ni16* with a mean shear value of 4.32 MPa.

Table 17: Panel shear strength (PS): Mean and standard deviation of plywood samples parallel and perpendicular to the face grain.

	Number of specimens	PS [MPa] ∥		PS [MPa] ⊥	
		mean	std dev	mean	std dev
E. nitens **16yr**	9	4.43	0.42	4.32	0.37
E. nitens **26yr**	30	5.21	0.46	5.22	0.49
E. globulus **33yr**	13	5.67	0.31	5.55	0.43
TasOak / E.ni16	2	4.99	0.23	4.74	0.06

Table 18: Characteristic shear strength of plywood samples parallel and perpendicular to the face grain.

	Number of specimens	f'_s [MPa] ∥	f'_s [MPa] ⊥
E. nitens **16yr**	9	3.64[a]	3.64[a]
E. nitens **26yr**	30	4.43	4.35
E. globulus **33yr**	13	5.07	4.75

Notes [a] K_s value based on n=10

Low shear strength values were observed for panels from all resources, with the exception of a (purchased) F14 panel that was tested with the trial panels as an additional control. Due to the implications of this poor result, additional samples from the same panels tested at UTAS were sent to EWPAA to provide certainty on the UTAS results. The EWPAA results provided confirmation of the poor shear values and the comparative shear values obtained at each test facility are provided in Table 19 below. The EWPAA values are generally lower than the UTAS results and differences may be attributed to natural variation between the samples tested from each panel.

Table 19: Comparative mean panel shear (PS) strengths, parallel to the face grain.

	Number of specimens	PS UTAS [MPa] mean	PS EWPAA [MPa] mean	UTAS - EWPAA [%]
***E. nitens* 16yr**	3	3.90	3.37	14
***E. nitens* 26yr**	3	4.59	3.57	22
***E. globulus* 33yr**	3	5.26	4.07	23
TasOak / E.ni16	2	5.03	4.20	17

Further shear testing was conducted at EWPAA on laminated beams made from additional test veneer from the *E.ni16* and *E.ni26*. Although little significance can be attributed to the results based on the small sample size, approximate F-ratings of F7 and F11 was suggested for the *E.ni16* material, whilst the *E.ni26* was F22. This result for beam shear (improved results for *E.ni26* and slight improvement for *E.ni16* suggests that poor glue-bonding may have contributed to the poor shear results observed in our trial plywood panels.

The poor shear results provide very low F-grade classifications the highest being an F8 for the *E.glob* resource. *E.ni26* shear strength is close to the minimum requirements for an F7, whilst the *E.ni16* fails to meet even F7 requirements for shear strength. Figures are very poor considering results obtained for stiffness and bending strength. As the shear test places high stress on the strength between fibres it could be postulated that checks and splits related to drying defects could have impacted the shear strength and provide some explanation for this result.

The testing of structural properties tends to suggest that the material produced from this resource will be shear limited. This may result in particularly low F-grades despite some very attractive bending results. If left unsolved this is a problem that will limit unpruned usefulness in structural products.

Janka hardness

All panels from the 2nd pressing trial were tested for Janka hardness (Table 20). As expected, *E.glob* was the hardest with a Janka rating of 8.5 kN followed by *E.ni26* with 6.8 kN, *TasOak / E.ni16* 4.90 kN and *E.ni16* with the lowest hardness rating (4.5 kN). The *E.ni16* possessed a low hardness compared with the *E.ni26* but is within the range of published figures for plantation *E.ni* in the same age class. These values compare well with the properties of *P.rad* classed as "soft" with a hardness rating < 5.5 kN, with a likely mean hardness ≈ 3.3 kN.

Table 20: Plywood Janka hardness, mean and standard deviation.

	Number of specimens	Janka Hardness [kN] mean	Janka Hardness [kN] std dev
***E. nitens* 16yr**	15	4.51	0.53
***E. nitens* 26yr**	30	6.75	0.99
***E. globulus* 33yr**	13	8.49	0.63
TasOak / E.ni16	2	4.90	0.24

Moisture Content

Table 21 shows the MC of the plywood samples determined according to AS/NZS 2098.1:2006. One sample from each panel was oven-dried immediately after testing panel shear strength. As specified in AS/NZS 2269.1:2008 MC should be in the range of 6 % to 15 % for a determination of structural properties. All species had MC close to the lower limit and *E.ni26* was slightly under the limit at 5.9 %.

Table 21: Moisture content of plywood panels

	MC [%]	
	mean	std dev
E. nitens **16yr**[a]	6.9	0.8
E. nitens **26yr**	5.9	0.4
E. globulus **33yr**	6.2	0.4
TasOak / E.ni16	6.8	0.1
TasOak / P.rad	*	*
P. radiata	*	*

Notes [a] Moisture content 2[nd] pressing trial
[*] No values available

Plywood F-Grade classification

Characteristic strengths and elastic moduli were evaluated in accordance with AS/NZ 4063 and AS/NZ 2269.2. F-grades were assigned using characteristic properties for F-grades as published in AS/NZ 2269.0 (Table 22). The poor shear strength with the highest achieved F-Grade of F8 (*E.glob* and *TasOak / E.ni16*) is of primary concern and is the limiting factor for stress grade classification of the tested plantation plywood panels.

Table 22: Plywood F-grade of modulus of elasticity, modulus of rupture and shear strength in both tested directions

	E_k		f'_b		f'_s	
	‖	⊥	‖	⊥	‖	⊥
E. nitens **16yr**	F11	F8	F11	F11	<F7	<F7
E. nitens **26yr**	F27	F27	F17	F17	F7	F7
E. globulus **33yr**	F34	F34	F34	F27	F8	F8
TasOak / E.ni16[a]	F17	F17	F27	F22	F8	F8
TasOak / P.rad	F22	F11	F17	F8	*	*
P.rad[a]	F14	F14	F22	F22	*	*

Notes [a] mean values instead of characteristic strength used due sample size < 10
* no values available

Assuming shear strength could be increased beyond the observed limiting levels through process optimisation (e.g. log-steaming and optimised veneer drying) the resources would be classified as shown in Table 23. *E.glob* would achieve the highest F-grade (F34), followed by *E.ni26* (F17), *TasOak / E.ni16* (F17) and *TasOak / P.rad* (F17). The *E.ni16* attained the lowest grade (F11) and compares only marginally with the standard pine resource in terms of observed stiffness and strength. However, selection of high stiffness family seed lots for future plantations in combination with the shorter rotation length (e.g. 15yrs versus 30yrs for pine) may improve economic viability especially if process optimisation can improve veneer recovery and quality. Furthermore, development of new plywood products using the young *E.ni* material in core layers could be viable.

Table 23: Plywood F-grade with the limiting factor for each resource

	F-Grade	Limiting Factor
***E. nitens* 16yr**[a]	F11	-
***E. nitens* 26yr**	F17	Bending MoR
***E. globulus* 33yr**[a]	F34	Bending MoR
TasOak / E.ni16	F17	Stiffness MoE
TasOak / P.rad	F17	Bending MoR
P.rad	F14	Stiffness MoE

Notes [a] most limiting factor shown for similar F-Ratings (bending MoR and stiffness)
- inconclusive

Acoustic correlations

AWV readings were taken with both the Hitman director HM200 and a Fakopp microsecond timer. As shown in Table 24 and
Table 25, correlations between AWV and veneer MoE_{dyn} and plywood MoE were similar at the log and billet level, i.e. no significant improvement was observed using billet AWV's. In agreement with Thomas *et al* 2009, the Hitman readings generally produced better correlations with MoE, however the results of the *E.ni26* data did not follow this trend.

Weak correlations were obtained for *E.ni16* and *E.ni26* between tree AWV and veneer MoE_{dyn} with an R^2 of 0.21 and 0.20 respectively. A moderate relationship was observed between tree AWV and veneer MoE_{dyn} for *E.glob* ($R^2 = 0.58$). Acoustic measurements on trees assess the stiffness of the outer fibres (based on the transit time of an impact signal between two probes, in this case 0.5 m and 1.7 m above the ground level). The better correlation for *E.glob* may thus be a result of the older age and slower growth rate for this resource i.e. the outer wood of this material may be more representative of the "billet average".

Log and billet AWV correlated moderately with veneer MoE_{dyn} for both *E.ni* resources (R^2 = 0.41-0.46), and correlated strongly with veneer MoE_{dyn} in *E.glob* (R^2 = 0.78-0.82). A similar trend was observed for correlations between log and billet AWV and plywood MoE with the exception of the poor correlation for the *E.ni26* resource (Table 25). Inclusion of green density i.e. using MoE_{dyn} (AWV^2 x Green Density) did not improve the resultant correlation and no explanation could be provided to explain the poor degree of correlation between AWV and plywood MoE for the *E.ni26* resource. A moderate correlation ($R^2 = 0.40$) was observed for the E.ni16 yr resource (Hitman data), with the best correlation between AWV and plywood MoE ($R^2 = 0.68$) observed at the billet level (Hitman data) for the *E.glob* resource.

Table 24: Correlation coefficient of correlation between AWV of Tree, Log, Billet and Veneer MoE

	E.ni16 (n=361)		E.ni26 (n=49)		E.glob (n=18)	
	R^2_{Hit}	R^2_{Fak}	R^2_{Hit}	R^2_{Fak}	R^2_{Hit}	R^2_{Fak}
Tree AWV vs. Veneer MoE	*	0.21	*	0.20	*	0.58 (4)
Log AWV vs. Veneer MoE	0.41	0.29	0.45	0.50	0.82	0.70 (1)
Billet AWV vs. Veneer MoE	0.42	0.36	0.46 (4)	0.51	0.78	0.74

Notes [0] number of outliers
* data not available

Table 25: Correlation coefficient of correlation between AWV of Tree, Log, Billet and Plywood MoE

	E.ni16 (n=23)		E.ni26 (n=30)		E.glob (n=13)	
	R^2_{Hit}	R^2_{Fak}	R^2_{Hit}	R^2_{Fak}	R^2_{Hit}	R^2_{Fak}
Tree AWV vs. Plywood MoE	*	0.24	*	0.01	*	0.39 (3)
Log AWV vs. Plywood MoE	0.44	0.44	0.14	0.16	0.65	0.54
Billet AWV vs. Plywood MoE	0.40	0.38	0.09 (1)	0.06 (1)	0.68	0.62

Notes [0] number of outlier
* data not available

1.1.1.1 Stiffness optimised panels from *E.ni16*

There were two pressing trials for the *E.ni16*. In trial 1 the position of sheets was random (for each tree), whilst in the second pressing trial panel stiffness was optimised by placing the stiffest sheets (from a given tree) at the outside of the panel where stress forces are greatest. As discussed previously there was strong evidence that six samples of the *E.ni16* plywood tested for MoE (2^{nd} Trial only) were affected by poor glue-bonding. Upon removal of these samples, there was a significant difference (α = 0.05) between the average MoE of the randomly selected panels (11.0 GPa) and the panels with optimized layup (13.0 GPa). It is noted that there was no significant difference (α = 0.05) in the average MoE_{dyn} from the billets used to make the sample panels, i.e. the difference in resultant panel stiffness can be attributed to the panel layup not the inherent stiffness of veneer from each log.

Table 26 summarizes the correlations between billet AWV and plywood MoE using *E.ni16* data. The correlation between billet AWV and plywood MoE was stronger for the stiffness optimized panels (Figure 59, $R^2 = 0.82$) than for the panels with randomized sheet layup (Figure 60, $R^2 = 0.53$). For pooled data the correlation between billet AWV and plywood MoE was weak ($R^2 = 0.18$, Figure 61) when the suspect samples were included. Removing the suspect samples from pooled data improved the correlation to moderate levels ($R^2 = 0.40$).

Table 26: Tree, log and billet AWV correlations with plywood MoE for the *E.ni16* resource, considering random, stiffness optimized and pooled data.

	Random (n=15)		Optimised ($n=8_a$)		Pooled (n=23)	
	R^2_{Hit}	R^2_{Fak}	R^2_{Hit}	R^2_{Fak}	R^2_{Hit}	R^2_{Fak}
Tree AWV vs. Plywood MoE	*	0.51	*	0.70	*	0.24
Log AWV vs. Plywood MoE	0.50	0.50	0.83	0.73	0.44	0.44
Billet AWV vs. Plywood MoE	0.53	0.52	0.82	0.80	0.40	0.38

Notes [0] number of outlier
* data not available
[a] reduced original sample number (15) due to glue-bond effect

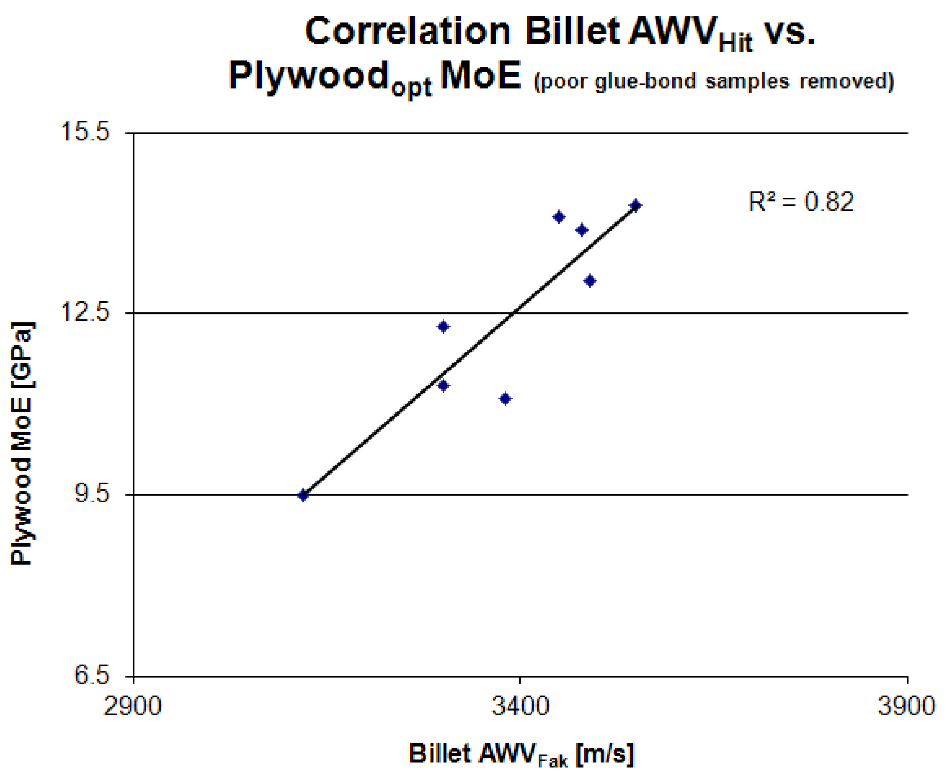


Figure 59: Correlation between billet AWV and plywood MoE pressed from stiffness optimised *E.ni16* veneer, excluding suspect samples

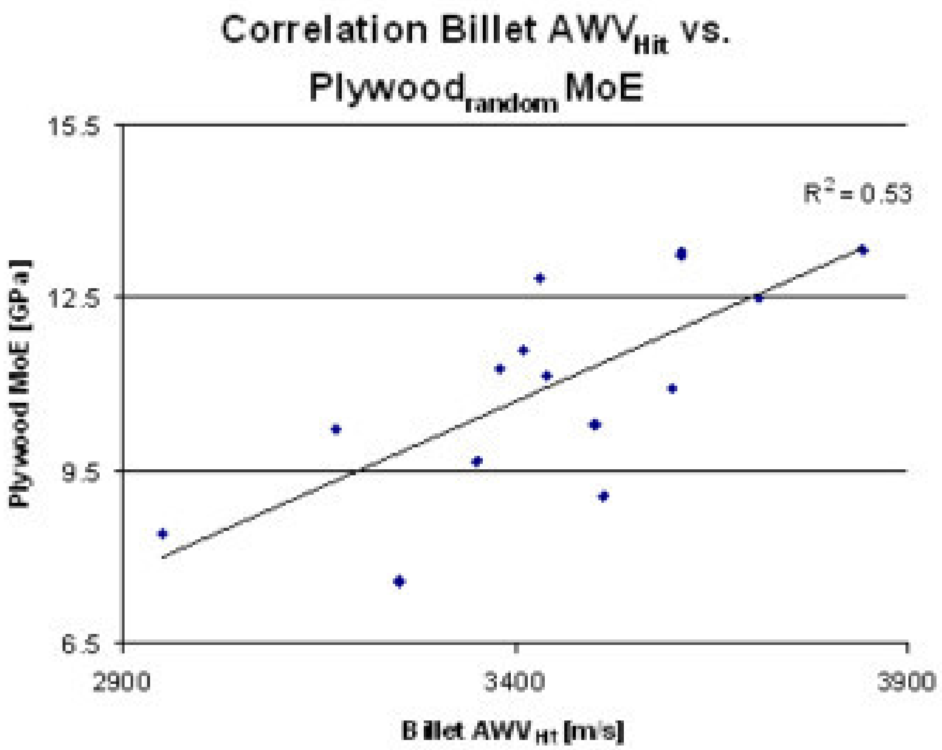


Figure 60: Correlation between billet AWV and plywood MoE pressed from randomly selected *E.ni16* veneer

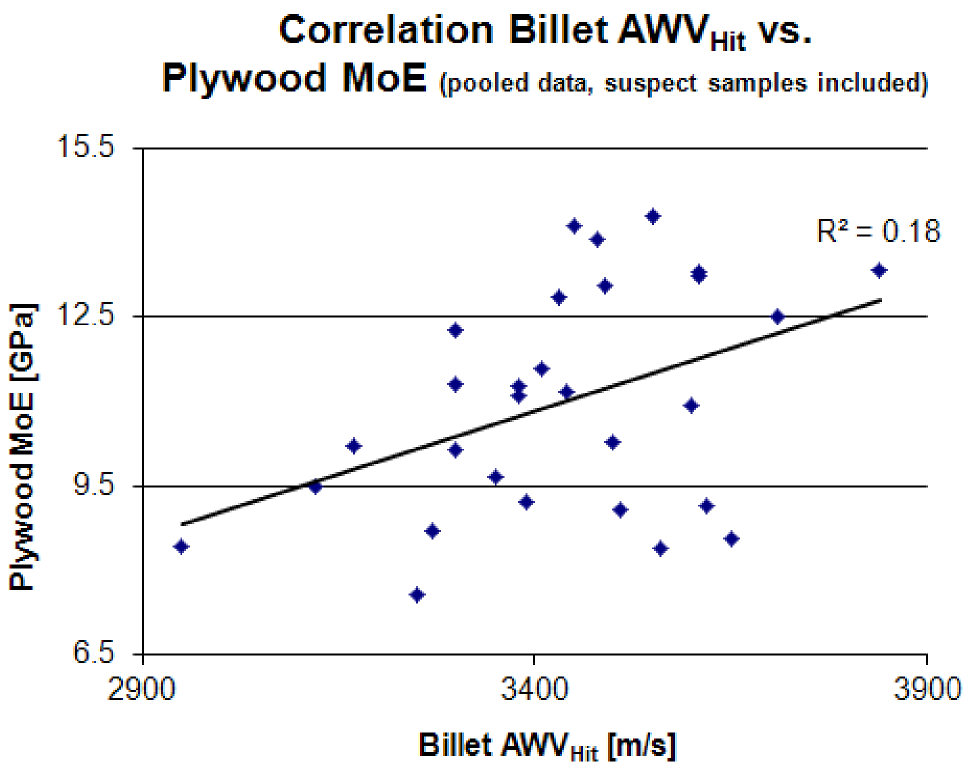


Figure 61: Correlation between billet AWV and plywood MoE using pooled *E.ni16* data, including suspect samples

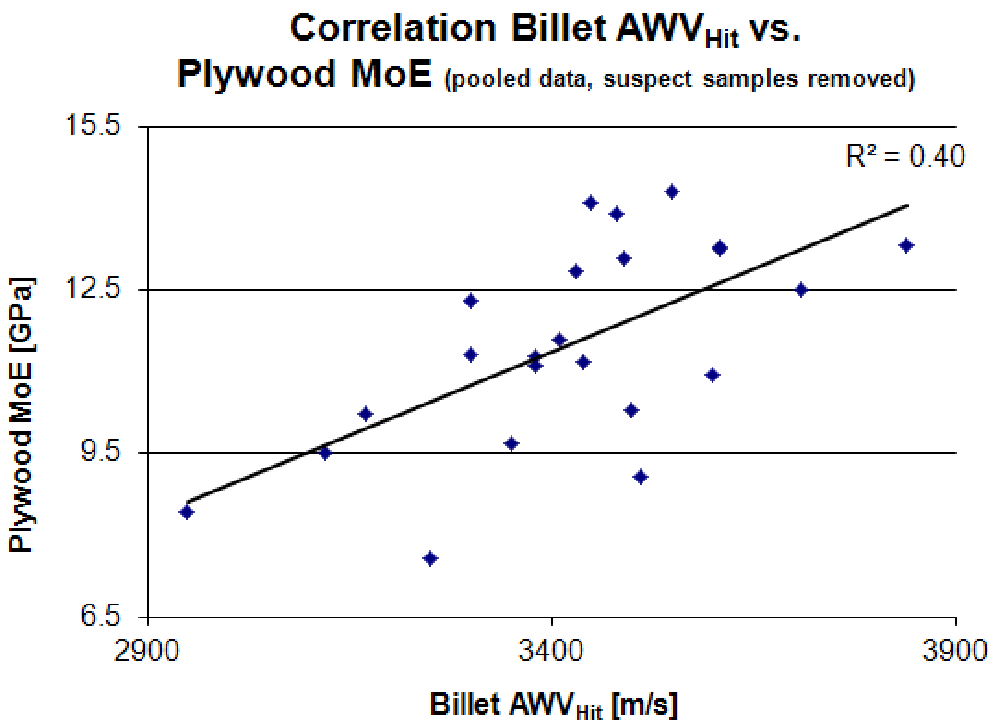


Figure 62: Correlation between billet AWV and plywood MoE pooled data with suspect samples removed

1.1.1.2 Tree, log and billet AWV correlations with veneer MoE_{dyn}

The correlations between tree, log and billet AWV and veneer MoE_{dyn} are shown in Figure 63 to Figure 65. Correlations at the tree level were poor with the exception of the moderate correlation observed for the *E.glob* data. Correlations are similar at the log and billet level, i.e. moderate for the *E.ni* resources (R^2 = 0.41 to 0.46) and strong for the *E.glob* data (R^2 = 0.78 to 0.82), suggesting segregation could be made at the log level, prior to merchandising.

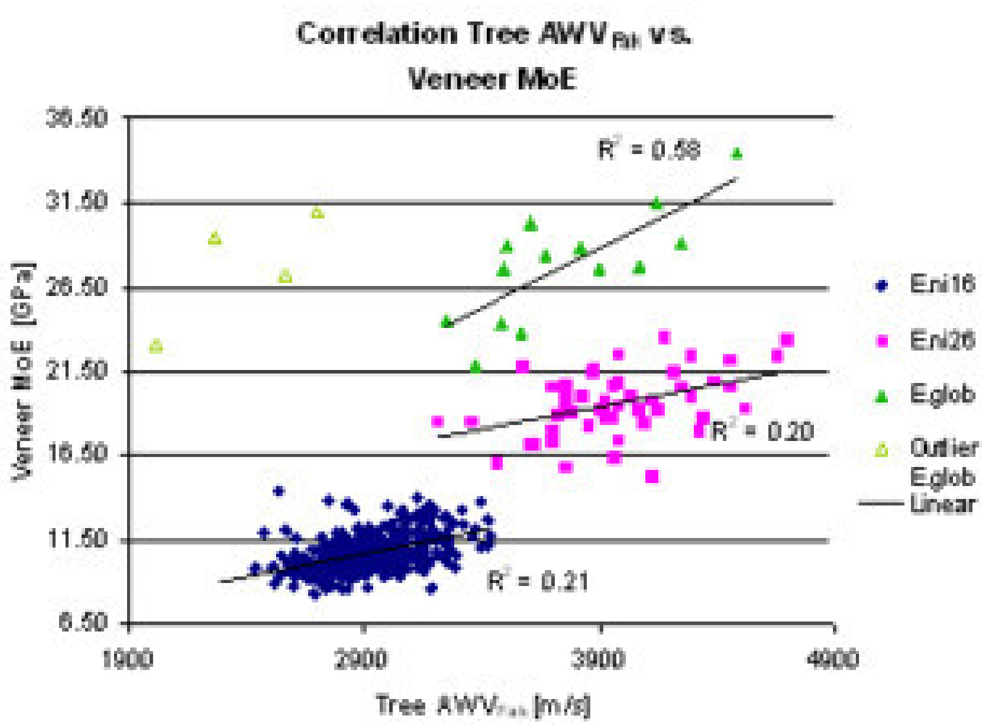


Figure 63: Correlation between tree AWV and veneer MoE of *E.ni16, E.ni26* and *E.glob*

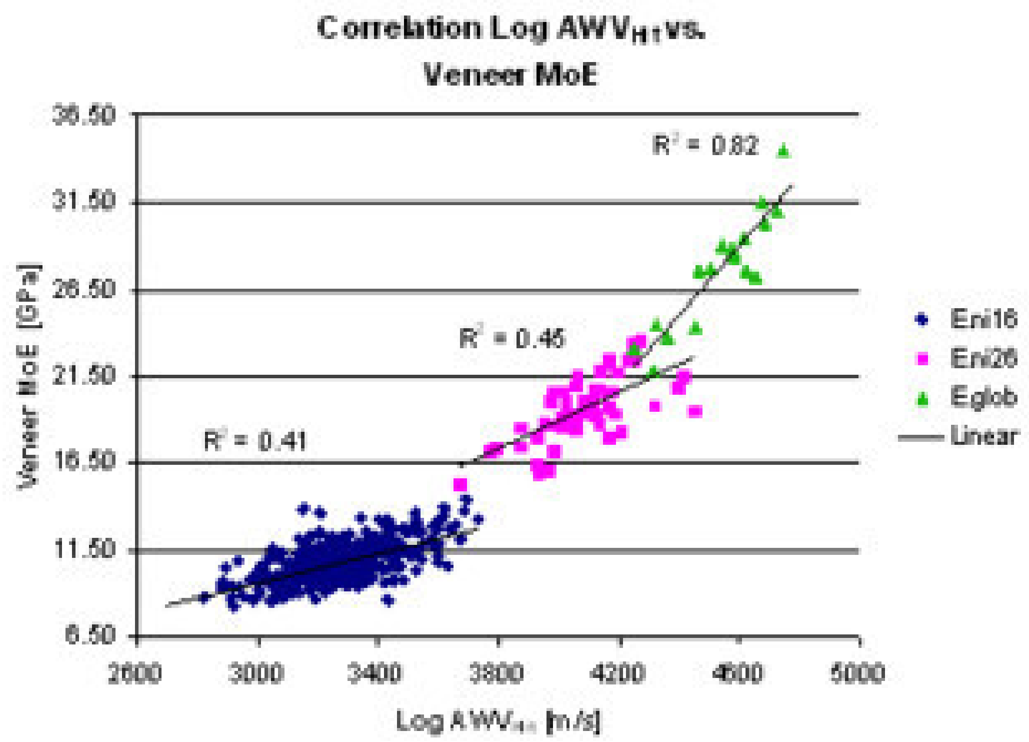


Figure 64: Correlation between log AWV and veneer MoE for E.ni16, *E.ni26* and *E.glob*

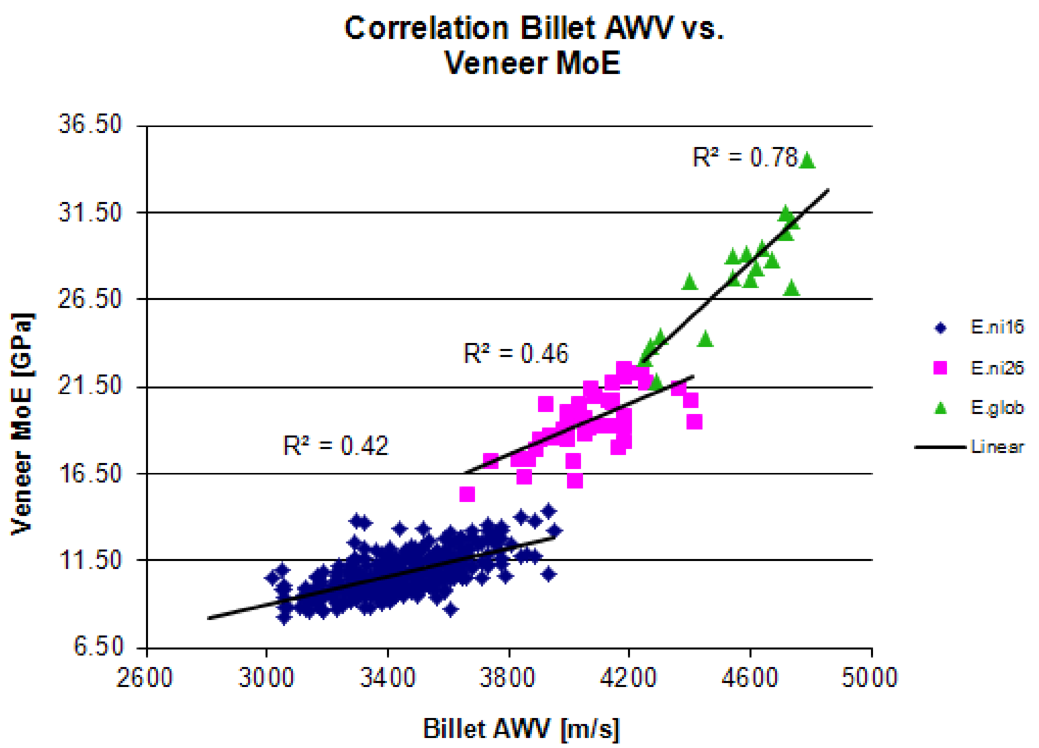


Figure 65: Correlation between billet AWV and veneer MoE_{dyn} for *E.ni16*, *E.ni26* and *E.glob*

1.1.1.3 Batching *E.ni16* logs using AWV to predict veneer stiffness

The *E.ni16* resource is the primary focus of this study and will be used to examine a potential acoustic sorting strategy. Given the weak correlation (R^2 = 0.21) at tree level, segregation is examined at the log level. Logs were segregated into three grades with average veneer MoE_{dyn} aligned with F-Grade limits for resultant plywood. Suitable threshold values were identified by ranking data according to increasing log AWV and adjusting the limits until reasonable values for mean MoE_{dyn} and standard deviation were obtained for each class (Figure 66). According to the threshold settings, 23% of the logs were classified as low stiffness failing to achieve F11 equivalent, 65% of the logs were classified as F11 and 12% were identified as higher stiffness logs producing veneer classified as F14 equivalent. Identifying logs not likely to meet F11 standards is critical due to the significant decline in product value below this point. Directing the low stiffness logs to non-structural processing streams would result in significant savings by eliminating non-productive processing, drying and grading time.

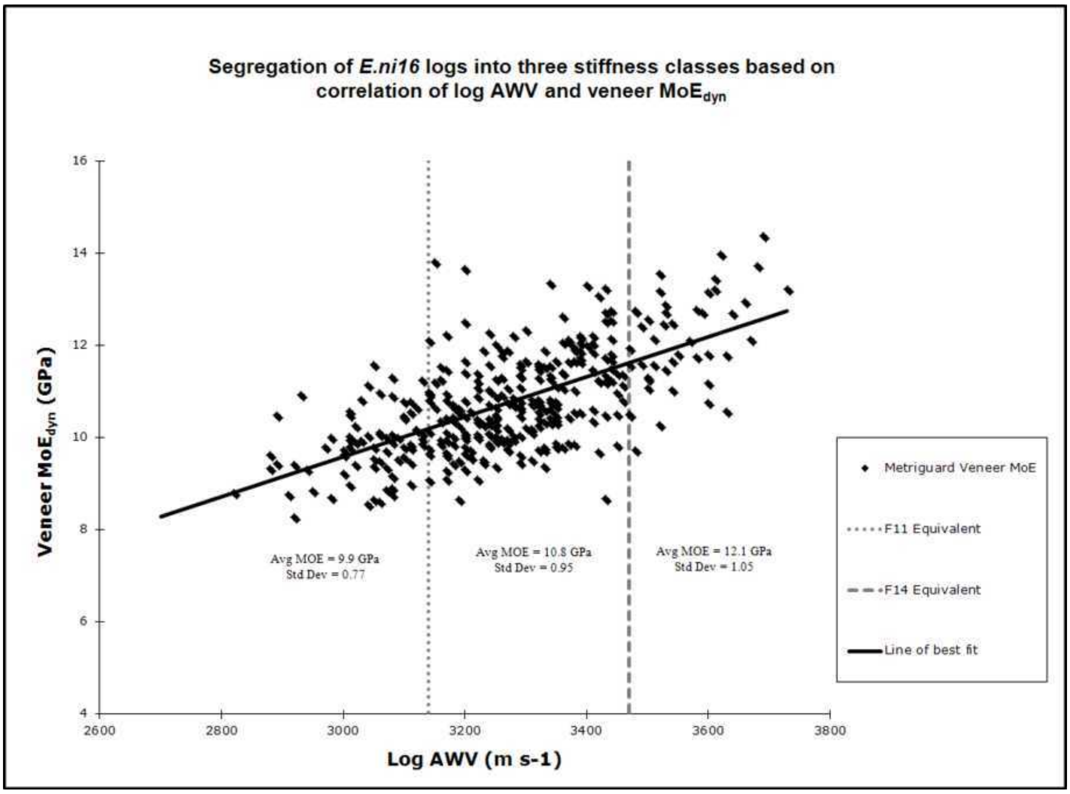


Figure 66: Segregation of E.ni16 logs into three stiffness classes based on correlation of log AWV and veneer MoE_{dyn}

1.1.1.4 Tree, log and billet AWV correlations with plywood MoE

The correlations between tree, log and billet AWV and plywood MoE_{dyn} are shown in Figure 67 to Figure 69. Correlations at the tree level were poor with no correlation evident for the *E.ni26* data. Correlations are similar at the log and billet level, i.e. moderate for the *E.ni* resources (R^2 = 0.40 to 0.44), strong for the *E.glob* data (R^2 = 0.65 to 0.68) and lacking for the *E.ni26* (R^2 = 0.09 to 0.14).

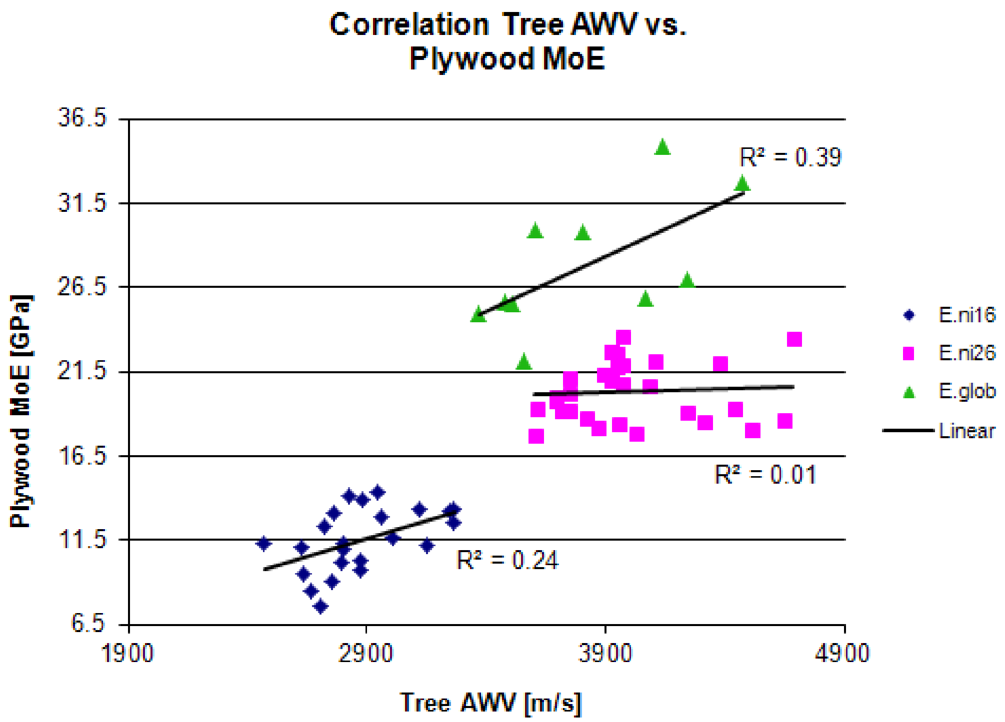


Figure 67: Correlation between Tree AWV and plywood MoE for *E.ni16*, *E.ni26* and *E.glob*

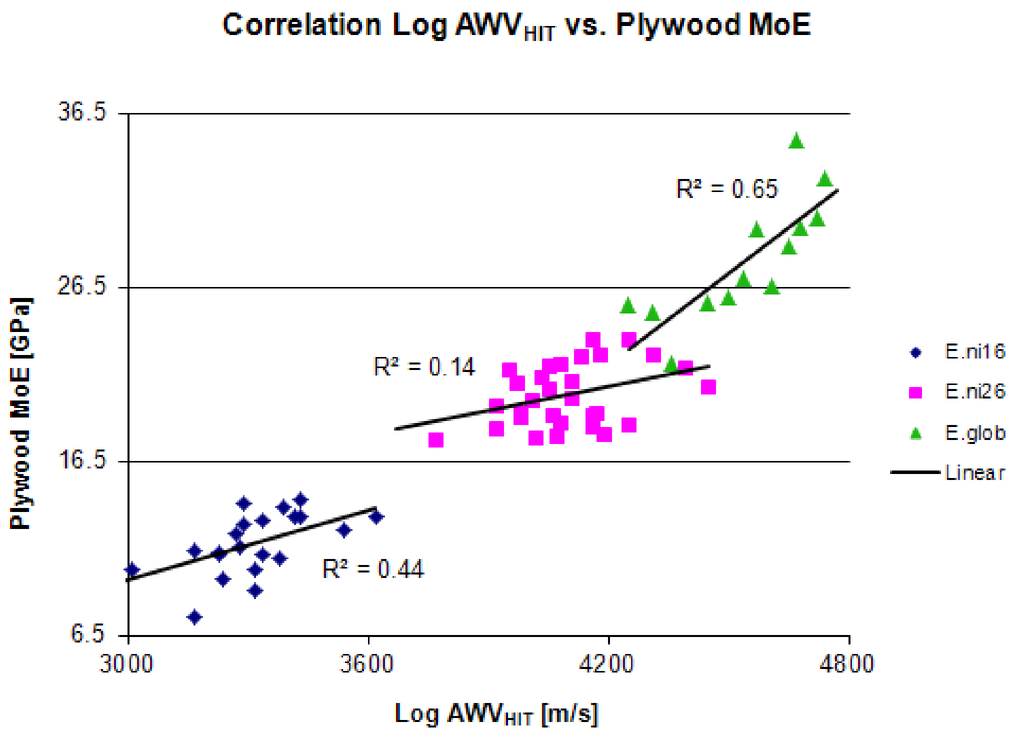


Figure 68: Correlation between log AWV and plywood MoE for *E.ni16*, *E.ni26* and *E.glob*

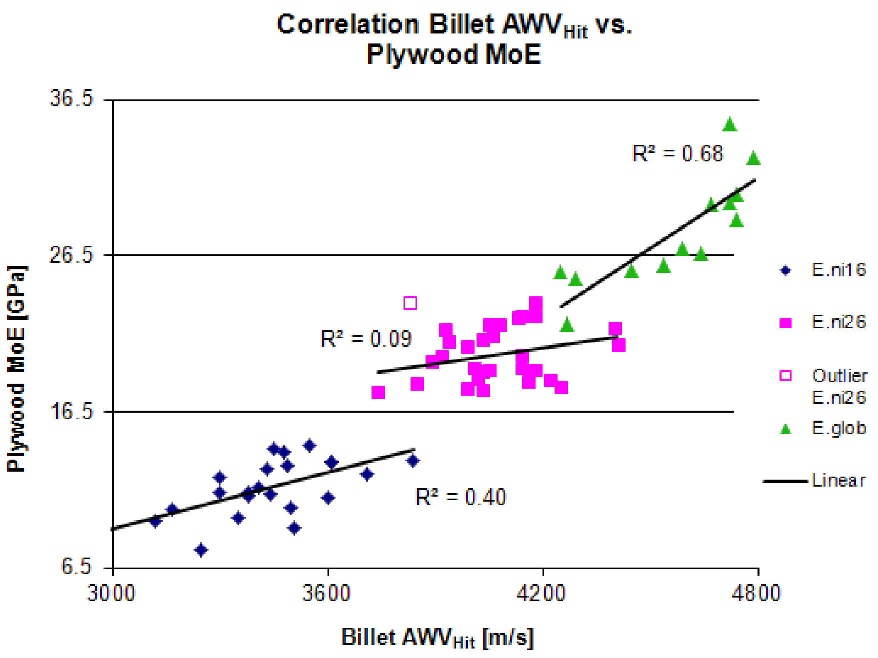


Figure 69: Correlation between billet AWV and plywood MoE for *E.ni16*, *E.ni26* and *E.glob*

1.1.1.5 Batching *E.ni16* logs using AWV to predict plywood stiffness

Although we only have a small sample (n=23) for AWV versus plywood MoE correlations, the procedure applied to veneer data was also applied to plywood data for indicative purposes. According to the threshold settings, 22% of the logs were classified as low stiffness failing to achieve “F11”, 48% of the logs produced “F11” panels and 30% were identified as higher stiffness logs producing “F14” panels.

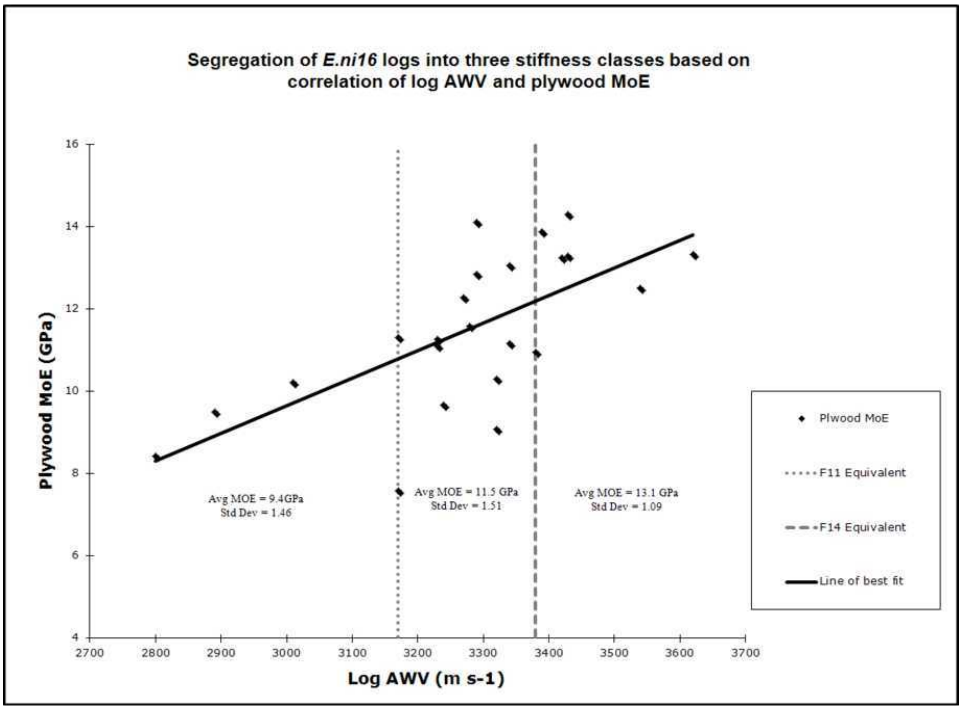


Figure 70: Segregation of E.ni16 logs into three stiffness classes based on the correlation of log AWV and plywood MoE

Genetic Parameters

E.ni16

In the *E.ni16* resource, there were highly significant (P<0.01) differences among races in DBH, standing tree, log and billet AWV and a significant (P<0.05) difference for NIR predicted CC. basic density, veneer sheet MOE and NIR predicted KPY were not significant at the race level. The Southern race of *E. nitens* had the most favourable values of veneer sheet MOE and AWV measures when compared to the other two races (see Table 27).

Table 27: Estimated Race means, F-ratio of difference among races, overall least-squares mean, additive variance, narrow-sense heritability (h^2_{op}) and coefficient of additive variation (CV_{add}) for each trait.

	Race means (se)							
Trait	**Connors**	**Northern**	**Southern**	**Race P-value**	**Overall least squares mean (se)**	**Additive variance (se)**	**h^2_{op} (se)**	**CV_{add}**
Basic density (kg/m^3)	476.5 (7.24)	468.6 (3.6)	470.4 (2.00)	ns	471.2 (2.77)	358 (111)***	0.47 (0.13)	4
Standing tree AWV (km/s)	3.31 (0.06)	3.4 (0.03)	3.54 (0.02)	***	3.42 (0.02)	0.034 (0.009)***	0.56 (0.13)	5
Log AWV (km /s)	3.15 (0.05)	3.18 (0.03)	3.28 (0.01)	***	3.20 (0.02)	0.028 (0.006)***	0.71 (0.13)	5
Billet AWV (km/s)	3.30 (0.06)	3.37 (0.03)	3.45 (0.02)	**	3.37 (0.02)	0.03 (0.007)***	0.72 (0.13)	5
Veneer sheet MOE (Gpa)	11.65 (0.39)	11.45 (0.21)	11.75 (0.11)	ns	11.62 (0.15)	1.12 (0.341)***	0.54 (0.14)	9
NIR Predicted KPY (%)	52.44 (0.32)	51.95 (0.16)	52.17 (0.09)	ns	52.19 (0.12)	0.70 (0.226)***	0.47 (0.14)	1.5
NIR predicted CC (%)	40.71 (0.31)	40.22 (0.15)	40.65 (0.09)	*	40.53 (0.12)	0.70 (0.213)***	0.50 (0.14)	2
DBH_{14} (CM)	22.52 (0.44)	23.02 (0.27)	24.15 (0.23)	***	23.23 (0.23)	7.14 (1.034)*	0.16 (0.02)	11

*P<0.05, ** P<0.01, ***P<0.001, ns = Not significant

All traits were observed to be under genetic control at the within race level. Family (and thus additive) genetic variation within races was highly significant (P<0.001) for standing tree, log and billet AWV traits, basic density and NIR predicted KPY and CC, as well as significant (P<0.05) for DBH (see Table 27). For traits significant at the race level, estimated narrow-sense heritability for DBH was 0.16; 0.50 for predicted CC, 0.56 for standing tree AWV, 0.71 for log AWV and 0.72 for billet AWV. For traits not significant among races estimated narrow-sense heritability for NIR predicted KPY was 0.50; 0.47 for basic density and 0.54 for veneer sheet MOE. Estimated coefficient's of additive variation (see Table 27) were low for NIR predicted KPY (1.5%) and NIR predicted CC (2.0%). All other traits showed low to moderate levels (4-9%) with DBH having the highest level at 11%.

Estimated additive genetic correlations (r_a) between all AWV measures, as well as between the AWV measures and veneer sheet MOE were strong, positive (r_a = 0.78 to 0.86) and highly significant (P<0.001) (see Table 28). Genetic correlations between all AWV measures and

NIR predicted KPY and NIR predicted CC were also strong, positive (r_a = 0.57 to 0.73) and highly significant (P<0.001). The additive genetic correlation between veneer sheet MOE and NIR predicted KPY was moderate (r_a = 0.44) and significant (P<0.05). Estimated additive genetic correlations between DBH and all traits under study were not significant, except for veneer sheet MOE which was shown to be significant (P<0.05). Basic density was strong and positively genetically correlated with all AWV measures and veneer sheet MOE (r_a = 0.75 to 0.87) and all correlations were highly significant (P<0.001). Weak additive genetic correlations estimates between basic density and NIR predicted KPY and NIR predicted CC were not significantly different to zero, but were highly significantly different to one.

Table 28: Inter-trait genetic correlations with standard errors shown in parentheses.

Trait	Basic density (kg/m^3)	Standing tree AWV (km/s)	Log AWV (km /s)	Billet AWV (km/s)	Veneer sheet MOE (Gpa)	NIR Predicted KPY (%)	NIR predicted CC (%)
Standing tree AWV (km/s)	0.75 (0.13)***						
Log AWV (km /s)	0.75 (0.12)***	0.89 (0.05)***					
Billet AWV (km/s)	0.79 (0.11)***	0.94 (0.05)***	0.99 (0.01)***				
Veneer sheet MOE (Gpa)	0.87 (0.14)***	0.78 (0.11)***	0.83 (0.08)***	0.86 (0.08)***			
NIR Predicted KPY (%)	0.06 (0.2) ns Diff to 1***	0.73 (0.14)***	0.57 (0.13)***	0.66 (0.12)***	0.44 (0.20)*		
NIR predicted CC (%)	0.09 (0.22) ns Diff to 1***	0.64 (0.14)***	0.57 (0.13)***	0.62 (0.12)***	0.37 (0.19) ns	0.96 (0.02)***	
DBH_{14} (cm)	0.44 (0.20) ns	0.19 (0.19) ns	0.35 (0.18) ns	0.28 (0.18) ns	0.53 (0.18)*	0.15 (0.21) ns	0.17 (0.20) ns

*P<0.05, ** P<0.01, ***P<0.001, ns = Not significant

Significant differences among the *E.ni16* races present in the trial were observed in all AWV stiffness prediction measures (i.e. standing-tree AWV, log AWV and billet AWV), in DBH and NIR predicted CC, while race differences in basic density and NIR predicted KPY and veneer sheet MOE were not significant (see Table 27). The Southern race had the highest mean values for AWV traits, NIR predicted CC and DBH indicating that these traits could be genetically exploited at this level. These and other traits favourable for solid-wood products have been previously identified as superior in this race, when compared to neighbouring races from central Victoria (Blackburn et al. 2010; Hamilton et al. 2009). At within race level, likelihood ratio tests showed highly significant (P<0.001) additive genetic variance for all traits measured except DBH, which had a significant (P<0.05) level of additive genetic variance. As all traits were shown to be under genetic control (see Table 27), then all potential AWV selection criteria, final stiffness of the RPV sheet, basic density, growth and desirable pulpwood traits would be amenable to genetic improvement in *E. nitens.*

In the *E.ni16* trial, estimated additive genetic correlations in the between all AWV measures (standing-tree, log and billet) and veneer sheet MOE were strongly positive and highly significantly different from zero (see Table 28). Further, estimated genetic correlations between all AWV measures and basic density were also strongly positive and highly significantly different from zero. Estimated genetic correlations between basic density and both predicted NIR traits (KPY and CC) were not significantly different from zero, but highly significantly different to one (see Table 28), indicating no relationship exists between these traits. However, estimated additive genetic correlations between AWV measures and NIR predicted pulpwood traits (KPY and CC) were strongly positive and highly significant. Estimated additive genetic and phenotypic correlations between DBH and all AWV measures and between DBH and predicted NIR traits (KPY and CC) were generally weakly to moderately positive and not significant. The additive genetic correlation estimate between DBH and veneer sheet MOE was moderately positive and significant, possibly due to the selection of the veneer sheet for study being taken from the outer circumference of the peeled log.

E.ni26

In the *E.ni26* trial, no significant effect of family was detected in the study trees for the growth and wood quality traits examined (Table 29). This sample represented only a small cross section of the geographic and thus genetic range (all Southern race) of *E. nitens*. However, it does give some insight to the potential for the species in the production of RPV. All the wood quality traits assessed were substantially higher in trees from this trial compared to trees in the *E.ni16*. Many factors could have contributed to this difference including genetics, environment, silviculture, age and sampling strategy. Growth and wood quality traits in plantation eucalypts can be significantly affected by site (Hamilton et al. 2009), age (Stackpole et al. 2010b) and sampling method (Blackemore et al. 2010) and this needs to be further investigated to determine the relative strengths of those factors on *E. nitens* RPV quality. The results from the *E.ni16* trial show genetics does play a significant role in affecting wood quality and breeding can improve desirable traits in *E. nitens*.

Table 29: Means, standard errors and the significant of the family effect on tree and wood properties of the *E.ni26* trees selected for the study.

Trait	Mean	Standard error	Family effect P value
Basic density (kg/m^3)	520	0.006	ns
Standing tree AWV (km/s)	4.05	0.05	ns
Log AWV (km /s)	4.08	0.02	ns
Billet AWV (km/s)	4.04	0.04	ns
Veneer sheet MOE (Gpa)	23.3	0.4	ns
NIR Predicted KPY (%)	55.5	0.2	ns
NIR predicted CC (%)	44.9	0.2	ns
DBH_{14} (cm)	40.1	0.6	ns

ns = Not significant

E.glob

E. globulus generally has higher basic density, strength characteristics (McKinley et al. 2002) and pulp yield (Beadle et al. 1996) compared to *E. nitens*. All wood quality traits in the *E.glob* material were substantially higher than those in material from either *E. nitens* trial. In the *E.glob* material, provenance had a significant effect on all wood quality traits except standing tree AWV and veneer sheet MoE (Table 30). The provenance effect on DBH was not significant either, but this would reflect the bias toward selecting trees of size suitable for the study. Provenance rankings for basic density and Kraft pulp yield in this study were concordant with those found by Stackpole et al. (2010b) and these cover a wide range of values within the species and are traits under moderate genetic control and can be improved through breeding (Stackpole et al. 2010a).

Table 30: Provenance means, standard errors and the significant of the provenance effect on tree and wood properties of the *E.glob* trees selected for the study.

	Trait and their means (standard errors)							
Provenance	**DBH (cm)**	**Basic density (kg/m^3)**	**Standing tree AWV (km/s)**	**Log AWV (km /s)**	**Billet AWV (km/s)**	**Veneer sheet MOE (Gpa)**	**NIR Predicted KPY (%)**	**NIR predicted CC (%)**
Geeveston	32.5 (1.2)	591 (14)	4.04 (0.33)	4.68 (0.06)	4.74 (0.07)	34.5 (2.0)	60.4 (0.7)	49.3 (0.7)
Jeeralang	35.4 (1.2)	623 (14)	3.13 (0.33)	4.42 (0.06)	4.43 (0.07)	28.8 (1.7)	55.6 (0.7)	45.7 (0.7)
King Island	36.0 (1.2)	554 (14)	3.83 (0.33)	4.59 (0.06)	4.60 (0.07)	30.1 (1.7)	59.2 (0.7)	48.4 (0.7)
Otway Ranges	34.0 (1.2)	635 (16)	3.01 (0.33)	4.62 (0.06)	4.64 (0.07)	30.7 (2.4)	57.5 (0.8)	48.1 (0.7)
St Helens	34.0 (1.2)	605 (14)	3.56 (0.33)	4.45 (0.06)	4.44 (0.07)	29.6 (1.5)	55.1 (0.8)	45.7 (0.7)
P value for provenance effect	ns	**	ns	*	*	ns	***	***

*P<0.05, ** P<0.01, ***P<0.001, ns = Not significant

Acoustic wave velocity and veneer sheet stiffness

Veneer sheet MOE is commonly used to determine the stiffness and thereby quality and value of plywood end-products and LVL panels (Meder et al. 2002). Acoustic wave velocity in logs and the stiffness of plywood boards has been found to be closely related and previous mill studies have confirmed the strong mathematical relationship between acoustic velocity and wood stiffness (Carter et al. 2006; Dickson et al. 2005; Farrell et al. 2008). AWV can be measured quickly using commercially available tools, allowing a large number of trees, logs or billets to be quickly assessed.

In the *E.ni16* trial, veneer sheet MOE estimated genetic parameter results showed highly significant additive variance (P<0.001), high narrow sense heritability (0.54) and a coefficient of additive genetic variation of 9%, indicating plantation grown *E. nitens* veneer sheet MOE could be improved by selective breeding. Acoustic wave velocity was assessed on standing trees, logs and billets to gauge how effective AWV is as a predictor of veneer sheet MOE.

Independently all AWV measures in the *E.ni16* material had highly significant additive genetic variance (P<0.001) and estimated narrow sense heritabilites ranged from 0.56 in the standing tree, to 0.71 in the log and 0.72 in the billet. This was consistent with heritabilities of AWV measures in other eucalypt species (Raymond et al. 2008) and supported testing the relationship between all AWV measures and veneer sheet MOE. In this study strongly positive ($r_a = 0.78 – 0.86$) and highly significant (P<0.001) additive genetic correlations estimates between AWV for all measures and veneer sheet MOE, demonstrated that the final engineered wood product (e.g. plywood and LVL) stiffness could be improved by selectively breeding *E. nitens* with higher standing tree AWV.

Acoustic wave velocity and pulpwood traits

To-date most *E. nitens* breeding programs have focused on selecting traits for Kraft pulpwood production, which include increased volume production, higher basic density and higher pulp yield (Borralho et al. 1993; Greaves et al. 1997; Hamilton et al. 2008; INFOR 2004). However, if KPY, AWV measures and basic density are under genetic control and favourable correlations are observed between standing-tree AWV and NIR predicted KPY and basic density, then standing-tree AWV could be adopted as a selection trait to improve desirable pulpwood traits in *E. nitens* breeding programs. However, more work on a bigger sample size will be needed to evaluate the effectiveness of using standing tree AWV to improve KPY in *E. globulus* breeding programs.

Recently multispecies and multisite calibrations have been used to predict KPY values from NIR spectra obtained from wood samples and the method has been proposed for the non-destructive ranking of families or clones in tree breeding programs (Downes et al. 2009). Estimated results from the *E.ni16* material showed NIR predicted percentage amounts of KPY (least squares race mean = 52.2 %) and CC (least squares race mean = 40.5 %) were consistent with previous studies in *E. nitens* (Hamilton and Potts 2008). Strong to moderate heritabilities in the *E.ni16* material (KPY = 0.54, CC = 0.54) and highly significant additive genetic variance (P<0.001) indicated these traits were under favourable genetic control, but low coefficients of additive variation of (1.5% for KPY and 2% for CC) means they would be difficult to select for and improve. Earlier phenotypic studies by Wright et al. (2003) identified a relationship between AWV and KPY, with later studies indicating AWV is significantly correlated with KPY in *E. nitens* (Downes et al. 2008; Downes et al. 2006).

In the *E.ni16* trial, estimated additive genetic correlations between all AWV measures and KPY and between all AWV measures and CC were moderate to strongly positive ($r_a = 0.57 – 0.73$) and highly significant (P<0.001), supporting the use of AWV standing tree acoustic wave as a selection criteria in breeding programs aiming to improve both KPY and CC.

Basic density

In the *E.ni16* material, the basic density value of least squares mean for races (see Table 27), estimated genetic parameters (highly significant additive variance P<0.001 and a narrow sense heritability = 0.47) and a relatively low estimated coefficient of additive variation (4%) were similar to previous estimates in *E. nitens* (Hamilton et al. 2008; Hamilton and Potts 2008). The strongly positive and highly significant estimated additive genetic correlation seen between basic density and veneer sheet MOE ($r_a = 0.87$, P<0.001), indicates selective breeding for basic density would also improve veneer sheet stiffness in *E. nitens*. Raymond et al. (2010) investigated whether the relationship between AWV and pulp-yield is due to basic density or other chemical differences in wood structure. Their studies showed strong relationships between AWV and basic density and between AWV and pulp yield, but found the relationship between basic density and pulp yield was not strong. Results from the *E.ni16* material support these findings, with an extremely weak and non-significantly different to zero, but highly significantly different to one estimated additive genetic correlation between basic density and NIR predicted KPY (r_a = 0.06) and between density and NIR predicted CC (r_a = 0.09), indicative of no relationship between these traits in *E. nitens*.

We can expect negligible disconnect in this study between basic density, NIR predicted KPY and NIR predicted CC estimated from samples taken from a disk extracted at 6 m tree height, and standing tree AWV was taken at 0.5 – 1.7 m tree height. In *E. nitens,* Raymond and Muneri (2001) observed minimum density at 10% tree height, increasing only slightly further up the tree (1.274 kg m^{-3} per 1% increase above 10% height level). Further, in the same species, Raymond et al. (2001) found NIR predicted pulp yield remained constant to approximately half the tree height and then decreased slowly with increased height.

Improving *E. nitens* veneer stiffness through genetic selection

Using the method described by Hai et al. (2008) the potential to increase veneer stiffness through genetic selection can be estimated. In the *E.ni16* material, by selecting the 20 trees with the highest veneer stiffness to stock a seed orchard, out of a nominal population of 500 trees, the offspring from the seed orchard would be expected to produce veneer with a mean stiffness 14% higher than the mean of the original 500 trees. In this case, the overall LS mean for *E.ni16* veneer sheet MOE was 11.62 Gpa (Table 27). The above selection scenario is predicted to increase the mean MOE to 13.24 Gpa.

Conclusions

Veneer

The high average MoE_{dyn} of *E.glob* and *E.ni26* veneer, indicate potential for production of structural peeled products (plywood and LVL) from those resources.

The lower density of the *E.ni26* veneer (643 kg/m^3) compared to *E.glob* (794 kg/m^3) could produce "high stiffness panels" (≥F17), with a lower weight penalty.

The visual grade recovery of D and better veneer sheets from the *E.ni* resource is low relative to current commercial operations however, the high stiffness of sheets that failed to make visual grade indicates that they could still perform well in structural applications where face grade sheets are not required. For example, knotty veneer could be used in formply products that are faced with a resin impregnated paper. For this application holes resulting from loose knots would need filling prior to application of surface paper – automation of such activity is feasible in modern plants.

Although high percentages of *E.ni* veneers failed to meet minimum visual grade standards, significant volumes would still be suitable for structural products. To ensure optimal utilisation of plantation veneers in structural products UPT based stiffness grading should be applied.

Plywood

Glue-bond quality was generally promising for all resources considering poor results associated with previous "in-house" hardwood results. Bond quality was good for the older *E.ni26* and *E.glob* resources with 100% A-bond pass rate and acceptable bond quality scores. Glue-bond quality was promising for the *E.ni16* resource (73% pass rate in trial 1), however, further work is required to optimise gluing parameters for this resource.

Based on estimated characteristic MoE values, plywood panels with F-ratings of F34, F27 and F11 (parallel to the face grain) was produced from *E.glob*, *E.ni26* and *E.ni16* respectively.

Based on estimated characteristic MoR values, plywood panels with F-ratings of F34, F17 and F11 (parallel to the face grain) was produced from *E.glob, E.ni26* and *E.ni16* respectively.

Based on estimated characteristic shear strength values, plywood panels with F-ratings of F8, F7 and <F7 (parallel to the face grain) was produced from *E.glob*, *E.ni26* and *E.ni16* respectively. The poor shear values are the limiting properties for F-Grade classification. If left unsolved this is a problem that will limit the usefulness of unpruned material for use in structural products. Future research should examine process improvement opportunities for these plantation species (e.g. log-steaming and veneer drying) to determine benefits in veneer quality and potentially shear properties of resultant plywood.

E.glob was the hardest with a Janka rating of 8.5 kN followed by *E.ni26* with 6.8 kN, *TasOak / E.ni16* 4.90 kN and *E.ni16* with the lowest hardness rating (4.5 kN). These values compare well with the properties of *pinus radiata* (classed as "soft" with a hardness rating < 5.5 kN), with average hardness around 3.3 kN.

Assuming shear strength could be increased beyond the observed limiting levels through process optimisation the resources tested would classify with F-Grades of F34 (*E.glob*), F17 (*E.ni26*), F11 (*E.ni16*), F17 (*TasOak / E.ni16*) and F17 (*TasOak / P.rad*).

Viable processing of short-rotation (15yr) unpruned *E.ni* will further depend on increasing average stiffness properties through genetic selection of superior families, use of acoustic sorting strategies to exclude low stiffness logs, process optimisation and recovery improvements as well as stiffness grading of veneers to facilitate stiffness optimised panels that use high stiffness veneers on outer layers and low stiffness veneers in core layers.

Acoustic correlations and log segregation strategies)

The strongest correlations were observed for the *E.glob* resource. Stiffness optimised plywood panels correlated better with log AWV than panels with a randomized layup.

Tree level correlations were weak for the *E.ni* resource (R^2 = 0.20-0.21 with veneer and R^2 = 0.01-0.24 with plywood MoE). Tree level correlations were moderate for *E.glob* (R^2 = 0.58 & 0.39 for veneer and plywood MoE respectively possibly a result of more uniform wood properties from older trees on a slow growing site.

Log and billet AWV correlated moderately with veneer MoE_{dyn} for *E.ni* resources (R^2 = 0.41-0.46), and correlated strongly with veneer MoE_{dyn} in *E.glob* (R^2 = 0.78-0.82). A similar trend was observed for correlations between log and billet AWV and plywood MoE for *E.ni*.

Correlations at log level were similar to those at billet level indicating potential for acoustic segregation of long logs prior to merchandising.

No significant correlation was observed for *E.ni26* AWV versus plywood MoE.

There was no significant difference in average *E.ni16* veneer MoE_{dyn} of billets pressed in trial 1 (randomised sheet placement) and trial 2 (stiffness optimized sheet placement). However, a significant difference (α = 0.05) was observed between the average MoE of panels from the two layups (11.0 GPa for randomised Vs. 13.0 GPa optimised layup).

The large dataset gathered for the *E.ni16* (the focus of this research) was useful in correlating AWV to veneer stiffness facilitating the segregation of logs into three stiffness classes. The practical benefit from an acoustic segregation strategy is likely to be the ability to identify low and high stiffness logs at the extremes of the stiffness distribution and utilise them appropriately. Based on the results of this study 79% of logs classified as low stiffness (according to AWV) produced “F8 equivalent” low stiffness veneers (i.e. < 10.5 GPa). 93% of the high stiffness logs (according to AWV) produced veneers with stiffness greater than F11 (i.e. >10.5 GPa) with 53% making F14 equivalent veneer (>12 GPa).

Although sample numbers were small for AWV Vs. plywood MoE correlations, the acoustic segregation potential is explored for interest. Again the practical benefit from an acoustic segregation strategy is likely to be the ability to identify low and high stiffness logs. Based on the results of this study 80% of logs classified as low stiffness (according to AWV) produced F8 low stiffness panels (i.e. < 10.5 GPa) whilst 100% of the high stiffness logs (according to AWV) produced panels with stiffness greater than F11 (i.e. >10.5 GPa) with 86% making F14 panels (>12 GPa).

Implications for breeding programs

This study showed that there is a genetic basis to variation in both wood stiffness and pulpwood selection criteria and objective traits in *E. nitens* (see Table 27). In *E. nitens*, the estimated genetic correlations between standing tree AWV and the objective traits: veneer sheet MOE, NIR predicted pulpwood traits (KPY and CC), and basic density were highly significant and strongly positive (see Table 28), indicating a breeding objective could be developed to include traits that would simultaneously improve desired properties in both pulpwood and RPV engineered wood products. It also suggests that *E. nitens* breeding programs that have been focused on improving basic density and Kraft pulp yield have also improved veneer quality. Standing tree AWV could be adopted as a non-destructive selection tool in *E. nitens* for improving veneer sheet stiffness, while also improving traits favoured by the pulpwood industry. Basic density, estimated to be favourably correlated with standing tree AWV and veneer sheet stiffness, showed no significant genetic relationship with NIR predicted pulpwood traits, further promoting the use of standing tree AWV as a preferred selection criterion in *E. nitens* breeding programs.

Recommendations for further research

This research has assessed veneer and plywood properties for plantation Eucalypts using current industry practices. The veneer peeling and drying process adhered to standard procedures applied to regrowth native forest Tasmanian Oak eucalypts (primarily *E. obliqua*), whilst the gluing and pressing regimes during plywood manufacture was based on standard *Pinus radiata* practice. It is therefore expected that process optimisation (of peeling, drying, gluing and pressing parameters) for the new plantation resource (i.e. *E. nitens*) would improve the results obtained.

Based on the results of this resource characterisation research the primary concern is with improving shear values of the resultant plywood panels. One significant area for improvement would be in the veneer drying process. Although the low MC (2.5%) of the *E.ni16* veneer is not necessarily of great concern it is likely that the rate of drying was beyond optimal rates for this resource. This may have exacerbated veneer checking and splitting and may have contributed to surface inactivation interfering with the glue-bonds (*E.ni16* glue-bonds were promising but require improvement).

Furthermore, the veneer drying process can be improved through segregation of green veneer into sorts according to MC. Many plywood plants use inline moisture meters on the peeler lathe outfeed (e.g. LightSORT^{TM}) to segregate dry heartwood from wetter sapwood material. This allows optimal drying schedules to be applied according to initial MC, resulting in improved control (i.e. variation) of final MC's and reduced energy consumption.

Additionally, due to the absence of facilities at the peeler plant utilised in this research logs were not steamed prior to peeling. Log-steaming is usually applied prior to peeling and would likely lead to improvements in veneer (and therefore) end product (e.g. plywood) quality. The benefits of log-steaming should be quantified for the plantation *E.ni* and *E.glob* resources.

The 33yr old *E.glob* sampled in this trial is beyond commercial rotation age but the high stiffness suggests that younger *E.glob* could be viable at least in terms of stiffness, and consequently, would be a worthy focus in future research. This further research should also be extended to a scale (such as the *E.ni16* sample size) where a genetic influence on veneer stiffness in *E. globulus* would have a reasonable chance of being detected.

Any comparison between resources needs to take into account the confounding effects that can be attributed to the environment, age and silviculture of the stands.

The use of pruned resources would reduce the number of knots and produce face grade veneers. Financial viability of peeling pruned resources would be linked to grade recoveries and product properties and should be quantified in future research.

It is considered that young unpruned *E. nitens* has low usefulness for higher value veneer and ply production. It will most likely produce short-grain veneer that is plentiful in supply and has a low sales price. The many knots cause roughness and can lead to excessive glue consumption in ply production and issues in the production of tongue and groove flooring. In addition, the piece size is typically small, reducing overall production efficiency.

Abbreviations

AS/NZS	Australian/New Zealand standard	
AWV	Acoustic Wave Velocity	Km/s
BD	Basic Density	kg/m^3
CC	Cellulose Content	%
CHH	Carter Hold Harvey Woodproducts Australia	
CSAW	Centre for Sustainable Architecture with Wood	
DBH	Diameter over bark at breast height (1.3 m)	cm
P	Density	kg/m^3
E	Characteristic value for modulus of elasticity	GPa
EWPAA	Engineered Wood Product Association of Australia	
E.glob	*Eucalyptus globulus*, blue gum	
E.ni	*Eucalyptus nitens*, shining gum	
E.ni16	16-year-old *Eucalyptus nitens*	
E.ni26	26-year-old *Eucalyptus nitens*	
Fak	Fakopp tool (UPT measurement)	
Fam	Family of seedlots	
ft	foot (1 ft = 0.3048 m)	ft
FT	Forestry Tasmania	
f'_b	Characteristic value for modulus of rupture	MPa
f'_s	Characteristic value for shear strength	MPa
GD	Green Density	kg/m^3
Hit	Hitman tool (UPT measurement)	
JAS-ANZ	Joint Accreditation System of Australia and New Zealand	
KPY	Kraft Pulp Yield	%
LED	Large End Diameter (of log)	mm
LPM	Low Pressure Melamine Panels	
LVL	Laminated Veneer Lumber	
MC	Moisture content	%
Met	Metriguard veneer grader	
MFA	Microfibril angle	°
MoE	Modulus of elasticity, bending stiffness	GPa
MoE_{dyn}	Dynamic modulus of elasticity	GPa
MoE_{stat}	Static modulus of elasticity	GPa
MoR	Modulus of rupture, bending strength	MPa
NIR	Near Infrared Reflectance	
Prov	Provenance of seedlots	
PS	Panel shear strength	MPa
P.rad	*Pinus radiata* D. Don, radiata pine	
SED	Small End Diameter (of log)	mm
TasOak	Tasmanian oak	
UPT	Ultrasonic propagation time	µs
UP	Unpruned silviculture	
UT	Un-thinned silviculture	

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